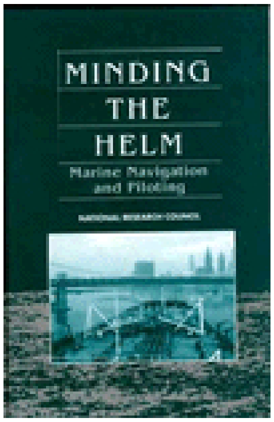

Minding the Helm: Marine Navigation and Piloting

Committee on Advances in Navigation and Piloting, National Research Council

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Minding the Helm

Marine Navigation and Piloting

Committee on Advances in Navigation and Piloting
Marine Board
Commission on Engineering and Technical Systems
National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Cover photo: Tanker westbound in New York's East River approaching the Manhattan Bridge. From the perspective of an individual on the ship's bridge, the vessel “fills” the channel. Visibility looking forward is generally good from a tanker with a superstructure aft, except for the water area ahead of the bow. (*USCG Vessel Traffic Service New York).*

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Preface

BACKGROUND

The safety of vessel navigation and piloting practices have been called to national attention by recent, well-publicized shipping disasters in which navigation and piloting have been contributing factors. Shiphandling, positioning, work practices, and communications in piloting waters have been identified as key causal factors in these accidents, calling into question the professional qualifications of merchant mariners and marine pilots and the effectiveness of marine navigation technology, shipboard navigation and piloting, and safety oversight. Also questioned are the programs and policies that led to current equipment requirements, skill development programs, licensing regimes, and manning and pilotage laws.

Safety concerns are accentuated by the large size of modern ships and barges transporting petroleum or other hazardous or dangerous cargoes. Cargo volume has increased the scale of the hazards to life, property, and the environment that could result from just one catastrophic marine transportation accident. However, these concerns must be considered in relation to the complex factors affecting marine transportation and the considerable reliance on efficient and cost-effective marine transportation for domestic and foreign trade. They also must be seen against the backdrop of the economic conditions that threaten the existence of the U.S. merchant fleet. Improvements to the marine navigation and piloting system too often are considered individually rather than collectively. Even when a broad range of options is considered, actual implementation is often fragmented and uncoordinated because of a patchwork of jurisdictions and no clear mechanism for balancing safety and economic objectives.

The Congress, in the Oil Pollution Act of 1990, reacted to deficiencies it perceived in the marine navigation and piloting system by requiring such measures as mandatory state pilotage and use of automatic dependent surveillance (ADS) systems in Prince William Sound and examination of shiphandling simulation as a means to improve the training of deck officers serving aboard tank ships. Also receiving congressional attention are advanced electronic navigation systems and application of aviation-like traffic control technology and procedures to U.S. ports and waterways. The National Transportation Safety Board continually has called for revision of federal pilotage laws to place all pilots under Coast Guard discipline, a move opposed by the states and state-licensed pilots. At the same time, the federal government and several states have enacted laws greatly increasing the economic cost to polluters for oil pollution incidents. Other states are considering extending state pilotage requirements to regulate the services of docking and mooring masters who hold, but do not operate under the authority of, federal pilot's licenses and endorsements.

The development of a suitable program to improve safety, which includes the application of advanced technologies, is complicated by a lack of cohesion and wide variations within the marine navigation and piloting system. These variations occur in terms of port, waterway, and river operating environments; vessel types, equipment, operating characteristics, loading, and manning; and professional qualifications. Interactions among these various factors result in safety problems that defy a simple solution. Pinpointing opportunities for improving safety requires careful consideration of risk, navigation and piloting practices, navigation technology, human systems, and public policy, as well as of the difficulty of proving the value and reliability of innovative practices and technologies in practical application. The system needs to be examined holistically, because a change in any aspect—training, manning, marine pilotage, systems maintenance, port and waterway operating environments, economics, government policies, and traditional approaches to navigation and change—affects the performance of the entire marine navigation and piloting system and the value of innovative solutions and technologies to improve safety. Proposed solutions must also guard against constraining development of other alternatives that may yield equivalent or greater value.

Against this backdrop of confounding factors and continuing public concern and controversy, the Coast Guard determined the need for an independent assessment. The Coast Guard requested that the National Research Council of the National Academy of Sciences conduct a comprehensive assessment of the state of practice of ship navigation and piloting and develop recommendations to improve it. In requesting the study, the agency indicated that the examination should address waterways management; marine pilotage, including the interaction of oceangoing ships with other commercial traffic in the nation's ports and waterways; and application of navigation technologies. The Coast Guard intends to use the technical information, analysis, and recommendations in its decision making concerning specific programs and regulations for administering marine safety and environmental protection responsibilities within the Coast Guard's domain.

NATIONAL RESEARCH COUNCIL STUDY

The National Research Council convened the Committee on Advances in Navigation and Piloting under the auspices of the Marine Board of the Commission on Engineering and Technical Systems. Committee members were selected for their expertise and to ensure a wide range of experience and viewpoints. The principle guiding the constitution of the committee and its work, consistent with the policy of the National Research Council, was not to exclude members with potential biases that might accompany expertise vital to the study but to seek balance and fair treatment. Committee members were selected for their expertise in naval science, marine pilotage, navigation technology, aviation systems, human systems, professional training and simulation, waterways management, and environmental safety and law. Academic, industrial, government, scientific, and engineering perspectives also were reflected in the committee's composition. Biographies of committee members are provided in Appendix A.

The committee was assisted by the U.S. Coast Guard, Maritime Administration, National Oceanic and Atmospheric Administration, and U.S. Army Corps of Engineers, all of which designated liaison representatives.

SCOPE OF STUDY

The committee was asked to (1) conduct a multidisciplinary assessment of the state of practice of ship navigation and piloting in the United States, with emphasis on navigation while entering and leaving ports; (2) identify advances in public policies, planning guidance, operational procedures, standards, training, and innovative technologies that have potential to improve safety and overall effectiveness of the marine navigation and piloting system; and (3) to make recommendations on research and development and on the role of government at all levels in advancing innovative applications of technology to improve ship navigation and piloting. The committee was to examine how changes in vessel systems, waterway systems, and human performance affect the basic navigation and piloting requirements in the port and on the vessel; to establish an improved technical basis for managing change in a competitive environment; and to improve navigation safety. Included in the scope of study were

- the changing character of vessel traffic (vessel types, vessel sizes, traffic density, port configuration and operation);
- the changing state of practice of vessel navigation and piloting, including technology advances and their implications;

- the changing roles of the vessel's master, officers, and crew (bridge complement); marine pilots; and shore-based traffic safety personnel;
- the effect of changes in technology on training, licensing, and performance;
- how changes in technology affect administration of marine navigation and piloting; and
- the government role in oversight and operation of the marine navigation and piloting system.

Although jurisdiction over pilotage was recognized as an important aspect of marine navigation and piloting, the assessment initially sought to focus on technical issues to provide a sound foundation for decision-making affecting the oversight and operation of the marine navigation and piloting system. It soon became apparent that the technical issues, including those pertaining to standards, training, licensing, pilot performance, and the application of advanced technology in piloting, were inexorably intertwined with pilotage administration and issues of governance. The committee determined that full assessment of administrative and technical issues was essential to fulfilling its charter and that these issues needed to be addressed in its conclusions and recommendations. The committee updated the study terms of reference to reflect this approach.

Pilotage for coastal towing industry vessels is an element of federal pilotage regulation and within the scope of study. The piloting of inland towing industry vessels is an ancillary area of interest insofar as these vessels interact with oceangoing vessels in coastal ports, connecting waters, and river systems. Marine traffic regulation, including vessel traffic services (VTS) as they interact with marine traffic and vessel operators, is a major issue and a central feature of the assessment. Also included in the scope of study are risk assessment factors underlying marine traffic safety and system performance, relevant lessons learned from prior examinations of the Great Lakes Pilotage System, economic and operating trends in marine transportation, and issues that might affect implementation of options to improve the state of practice of navigation and piloting.

Although tankers form a small portion of the world's merchant fleets, tanker operations are perceived by the public as the major marine transportation problem. Because of public interest in the causes, consequences, and implications of marine accidents that result in major pollution incidents, these marine accidents are usually far better documented and provide a more complete basis for determining what went wrong in the specific case and insight, if not complete answers, on systemic problems. Although these events constituted a major source of documentation, the navigation and piloting of the full range of merchant vessels is covered in order to assess systemic problems and options for improving the state of practice.

Excluded from the scope of study are navigation and piloting on the Great Lakes, navigation and piloting in inland navigation systems that do not support ship navigation, the navigation and piloting of naval vessels and Coast Guard cutters, the operation of recreational vessels in the vicinity of commercial traffic, and pilotage rate structures. However, pilotage administration for the Great Lakes, a Coast Guard responsibility, is addressed as an analogous system. Comprehensive assessment of implementation regimes for improvement options was also outside the scope of study.

The committee reviewed available data and literature and visited selected sites in North America and Europe to meet with local, regional, national, and international interests and to acquire firsthand insight. The committee also solicited data and views from marine pilots and docking masters; shipping and towing industry representatives; officials in local, state, and federal agencies and boards and commissions; waterways managers and vessel traffic regulators; public interest groups; and experts in maritime and pilotage law. A detailed trip report documents findings of the committee's delegation that visited European sites. A comprehensive background paper on VTS systems was prepared and used as the basis for the committee's assessment of marine traffic regulation. An extensive reference list was developed to facilitate identification and practical use of these materials.

REPORT ORGANIZATION

This report was prepared for an audience of state and federal government decision makers; marine licensing authorities; program administrators for navigation, piloting, and maritime professional development; marine pilots and docking master associations; pilotage boards, commissions, and state government departments responsible for pilotage regulation; the shipping and towing industries; port authorities; marine exchanges; and public interest organizations. The report provides an overview of the marine transportation system as an essential foundation for understanding the role of government, pilot associations and pilotage administrators, marine transportation companies, port authorities, and other organizations concerned with vessel operations. As an aid for readability, a chapter summary is provided at the beginning of each chapter.

Chapter 1 introduces issues in waterways management, marine pilotage, and navigation technology and describes the marine navigation and piloting system. It also describes changes affecting marine transportation, the controversy over pilotage and safety performance, and the need for assessing navigation and piloting.

Chapter 2 describes and analyzes marine pilotage practices and identifies the central features of an ideal pilotage system.

Chapter 3 describes and analyzes pilotage administration and identifies options for improving the state of practice.

Chapter 4 describes risk, risk assessment methodologies, and risk assessment in marine transportation. It also characterizes and discusses risk and safety performance factors in piloting waters, the operating environment, and the complexity of vessel maneuvering behavior. The chapter provides a safety performance analysis and offers options for improving risk and safety assessment in marine transportation.

Chapter 5 compares traffic regulation in the aviation and maritime environments and examines alternatives for improving waterways management in harbors, waterways, and rivers supporting ship navigation.

Chapter 6 examines traditional and emerging navigation technologies, their application, and their potential for improving safety performance.

Chapter 7 examines human systems, such as organizational systems; human–machine interface issues; and professional development, including the use of marine simulation.

Chapter 8 identifies research needs and suggests a research program.

Chapter 9 presents the committee's perspectives on the major changes that are in progress and that will drive the marine navigation and piloting system over the next decade.

Chapter 10 presents the committee's conclusions and recommendations.

The appendices provide essential background and technical information underpinning the analysis in the main body of the report.

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Executive Summary

INTRODUCTION

The marine transportation system has come under intense public scrutiny as a result of recent marine accidents involving substantial spillage of oil and damage to the marine environment. This report focuses on the role of marine navigation and piloting[1] in minimizing the number of accidents. It examines what can be done to reduce operational, economic, and environmental risks through improvements to navigation and piloting technology and practices in the nation's ports and waterways and their coastal approaches.

Overview of Marine Navigation and Piloting

Marine navigation and piloting involve complex, interdependent operations in a large sociotechnical system that encompasses waterways, vessels, navigation aids, and human operators. System elements are supported by an infrastructure for vessel and port management, pilotage, pilotage regulation, and professional development. Marine navigation and piloting occur in an operating environment characterized by extreme reliance on human performance, considerable diversity in geographic and hydrographic features, and great variability in operating conditions. How well this system performs in U.S. waters affects the nation's economy, the safety of vessels and their crews, the well-being of inhabitants near ports and waterways, and the natural environment. However, the

[1] Pilotage terms used in this report are found in Chapter 1.

system's structure and operation have not been extensively studied; moreover, interactions of its component elements are decentralized and highly localized. Efficient and effective interaction of these elements is essential for a highly reliable marine navigation and piloting system, which, in turn, is a key to enhanced maritime safety.

National and international authorities have worked for many years to improve safety in marine transportation. Improvements have been made in vessel design and construction, navigation aids, watchkeeping guidelines, professional training, and marine traffic regulation. Some of these advances have been voluntarily implemented by some operating companies either to reduce perceived operational and environmental risks or to improve economic performance. But in order to achieve universal adoption of these advances, establishment and enforcement of international conventions and national shipping laws and regulations is usually necessary. National requirements specify maintenance, outfitting, and crewing requirements for vessels flying the nation's flag.

Nations have taken actions under the terms of international treaties and standards as port-states to motivate improvements in the operating practices of foreign-flag ships. Nations have also used unilateral measures to exert direct influence over foreign-flag ships operating in their territorial waters. Port-state control actions and unilateral measures will become increasingly important insofar as the small size and economic competitiveness of the U.S. merchant fleet provide more limited leverage than in the past for negotiating improvements in international marine safety measures.

Nevertheless, questions remain as to how well modern ships, advances in navigation and piloting technologies, professional training, and official oversight have enhanced safety performance and met contemporary navigational, public, and environmental safety needs. By many measures, operational safety has improved over the past several decades, yet other indicators suggest that safety issues requiring resolution remain. Despite continuing efforts to improve operational safety, major shipping accidents involving all categories of commercial vessels continue to occur, some with great spillage of oil. Most of these accidents have been attributed to human causes rather than purely mechanical, environmental, or other causes. Public attention to safety in shipping has intensified in recent years, driven in part by major marine accidents resulting in oil pollution in ecologically sensitive areas. Public concern has also been heightened by the increased potential for damage inherent in increasingly larger ships and barges, the toxic nature of hazardous and dangerous cargoes originating in both foreign and domestic trade that are carried in bulk or in containers, and cargo volume.

Although marine transportation entails risks, "acceptable" levels of operational risk have not been established by marine safety authorities. Nevertheless, the contemporary public has demonstrated a strong lack of tolerance for marine accidents that result in major spillage of petroleum and hazardous cargoes or substantial loss of life. Laws and regulations aimed at curbing risks to the envi ronment have in turn stimulated considerable operating company interest in reducing economic risk through changes that improve operating practices and human performance.

Synopsis of Major Findings and Recommendations

The marine navigation and piloting system is for the most part safe, but it can be made safer. There are urgent and compelling reasons to do so. Reasons include (1) the potential consequences and costs of vessel accidents, (2) the accountability of carriers and mariners, and (3) the need to bring substandard ships up to acceptable operating conditions.

The marine navigation and piloting system could be enhanced substantially through specific improvements in marine pilotage and waterways management, as well as through maritime research and development, all of which would improve the safety performance of human systems. In particular, requirements and standards for pilotage of vessels, pilot development, and pilotage administration across the nation need to be addressed. In addition, the lack of pilotage requirements for harbor transits of foreign-flag ships in some ports and an absence of official accountability for some pilot services provided to such vessels are gaps that need to be addressed. Pilotage would benefit greatly from improvements in professional development programs, official oversight, and pilotage system administration. Constructive changes in each of these areas, designed to reduce operational and environmental risk, are needed to ensure full public confidence in pilotage.

Strong action by federal and, in the case of pilotage, state-level authorities is needed to improve:

- the capability to determine and correct systemic problems underlying human causal factors in marine accidents;
- the organizational structure for interdependent decision-making through measures that include application of vessel traffic services and other technological aids to marine traffic regulation;
- the quality, integrity, and consistency of pilot development programs and associated marine licensing;
- the accountability of pilotage systems and individual pilots, by closing gaps in official oversight and other measures; and
- the introduction and use of advanced navigation technologies.

Timely international action, which includes port-state control measures to enforce international standards, is needed to motivate action by flag states to correct substandard operating and manning practices for merchant vessels operating under each country's registry.

One set of steps toward a safer system is to develop formal professional standards for the provision of pilotage services and for the qualification and performance of pilots. This report recommends immediate action by all pilotage authorities to strengthen the existing federal and state pilotage requirements within their jurisdictions. It also recommends fundamental change in the federal and state pilotage systems, drawing on positive aspects from each approach, that would ultimately lead to a single pilotage system, encompassing both federal and state elements, for each local pilotage region.

Fundamental to improving safety in marine navigation and piloting is attention to human performance, new technology, and vessel traffic services (VTS). The report addresses each of these areas and contains recommendations for research and for application of new technologies to improve operational safety. Major recommendations are presented here in summary format. Chapter 10 contains the committee's complete conclusions and recommendations.

RISK IN THE MARINE OPERATING ENVIRONMENT

Major Findings

Although marine transportation entails risks, acceptable levels of operational risk have not been established by marine safety authorities. Risk factors are numerous and complex and their interactive effects are poorly understood; consequently, acceptable levels of risk are determined subjectively and vary widely among localities. Furthermore, because of the complexity of the marine operating environment, there are substantial differences in operational risk and exposure among vessels, even within the same port and waterways complex. Improved safety depends on understanding and effectively addressing these risk factors.

The available marine safety data are insufficient for quantitative assessments of risk and safety performance. The problem is exacerbated by the lack of an acceptable methodology for normalizing data across ports or regions to enable comparative analysis. For these reasons, casualty rates are imperfect indicators of safety performance. Few statistically valid assessments are publicly available about the probable contributions of various measures intended to improve navigational safety. Nevertheless, existing safety data, together with anecdotal information and expert opinions, provide a reasonable basis for informed problem identification and decision-making.

The impressions of marine pilots nationally and internationally and some data suggest that the numbers of substandard foreign-flag ships and crews are increasing and that some classification organizations (the bodies that establish and enforce standards for ship construction and maintenance on behalf of many flag states) are not applying adequate construction standards and are not ensuring adequate maintenance. However, there are no systematic national or international monitoring programs to detect vessels that increase risk. The full extent and effects of these safety hazards can only be surmised, but the evidence is sufficient to have stimulated national and international consideration of corrective measures.

Solutions that reduce risk in one operating environment may not achieve equivalent results in another. Inappropriately applied solutions can increase risk, as can a proliferation of marine equipment without technical or performance standards to guide their manufacture, configuration, and use. Although such risks can be reduced by establishing standards, by using ergonomic designs, and by educating and training mariners, it is more difficult to deal with unforeseen and unintended consequences of implemented solutions. Consequently, system-wide remedies to problems identified in marine navigation and piloting need to look beyond intended effects in order to identify and address the broader array of effects that might also result from the proposed solution.

The Oil Pollution Act of 1990 and subsequent rules and legislation substantially increased the economic cost of marine pollution incidents to polluters and provided for other measures intended to enhance marine safety and environmental protection. These changes have produced substantial incentives for shipping companies to reduce operational risk through improved ship construction, navigational procedures and equipment, and professional development. However, there is no systematic program to monitor shipping, economic, and safety performance trends or their relationship to marine safety laws and regulations or other options for improving marine safety. Such monitoring and assessment programs are essential.

Summary Recommendations

The U.S. Coast Guard, National Oceanic and Atmospheric Administration, Maritime Administration, and U.S. Army Corps of Engineers should cooperate in developing a standard methodology for assessing risk and safety performance and establish a continuing risk assessment program. They also should undertake a cooperative, multidisciplinary research program to investigate the interaction of the essential elements of a highly reliable, complete, and safe marine navigation and piloting system in order to better understand risk relationships. The Coast Guard should review and improve its capability to collect, analyze, and publish marine safety data on casualties, accidents, incidents, and near misses so that comprehensive safety performance data are available to guide improvements in marine navigation and piloting.

HUMAN SYSTEMS

Major Findings

Because human error is a major causal factor in marine accidents, countermeasures must focus on areas in which human actions are paramount: navigation and pilotage. Human performance can be improved by combining improvements in professional development, the organizational structure for decision-making, and technology.

There is growing concern over the professional development of ship's officers and pilots, especially those who direct and control the movements of tankers, and over the qualifications of licensed operators and pilots of coastwise towing vessels, especially tank barges. Programs for acquisition of theoretical knowledge and entry-level navigation and piloting skills range from training provided through accredited undergraduate programs at maritime academies to apprenticeships and on-the-job training. The last two play a major role in the shipping and towing industries, in ferry operation, and in marine piloting. The proficiency of crews of foreign-flag ships varies and is less certain than that of U.S.-flag crews. One consequence is that public safety and environmental protection authorities, especially at the state-level, increasingly rely on the services provided by marine pilots to reduce operational (and environmental) risk. This is done through the presence of the pilots and through the application of their expertise.

The expertise needed to serve as a marine pilot includes basic maritime theoretical knowledge and practical skills; local knowledge (such as routes, traffic conditions, seasonal variations); shiphandling skills; familiarity with technically advanced equipment; and the ability to assess the capabilities of masters, mates, and bridge personnel and to interact effectively with them. On-the-job training usually consists of progressive advancement in knowledge about routes and categories of ships. Although U.S. merchant marine officers are generally well qualified for navigation at sea, their capabilities for navigation and piloting in pilotage waters vary considerably based on navigation and bridge team experience, shiphandling opportunities, and continuing professional development opportunities. Modern shipboard responsibilities often do not allow masters and mates to develop the broad-based proficiency in vessel maneuvering needed to serve as independent marine pilots without an apprenticeship designed for this purpose. Towing industry experience normally provides extensive opportunities to handle vessels and to become familiar with local routes, but it does not provide shipboard experience. Therefore, an apprenticeship program is required even for seasoned mariners wishing to enter the marine pilot profession.

Standards for entry-level education, training, and continuing professional development for all pilots have tended to be more informal than formal, although well-developed curricula are used by some state pilot associations. Periodic refresher training has been gaining momentum, particularly with respect to shiphandling in special conditions. The number of pilot associations that have established continuing professional development programs for their members has increased considerably in recent years.

Some pilot associations have made substantial investments in continuing professional training programs (generally funded through pilotage fees) to enhance member proficiency and have used these programs for some time. Interest in such programs is growing throughout the piloting profession as a response to public concern over the safety of marine transportation.

Although informal monitoring of pilot performance is provided to some extent by colleagues, there is no systematic rectification or professional monitoring that could detect or prevent substandard performance in pilotage. Deficiencies in pilot knowledge and skills, or personal problems that adversely affect performance, are often identified only after a marine casualty occurs.

U.S. shipping companies and large towing industry companies generally have continuing professional development programs, as do a growing number of marine pilot associations. These programs, in the absence of standards to guide their development and use, vary in format and function. Most are not accredited or assessed for effectiveness. Marine simulation training is used in some programs to refine navigation and piloting skills, to promote and improve bridge team management, and to develop and practice emergency shiphandling procedures in a benign environment. Computer-based and manned-model simulation training technologies are widely considered useful, but their use in marine licensing currently is limited and evolving.

Official oversight of practical skill development is lacking in the federal marine licensing regime for masters, mates, and pilots. Professional development programs for mariners and marine pilots need to be improved, and each individual's navigation and piloting knowledge and skills need to be periodically refreshed, upgraded, and confirmed. Professional weaknesses and problems need to be identified and corrected before they cause or contribute to marine accidents, but formal advance detection measures are meager. Ship bridge simulation to detect weaknesses in professional abilities has been used to a limited extent by a few operating companies. After-the-fact official discipline by the Coast Guard or state pilotage authorities, while currently an important tool, is only effective if it also leads to remedial action.

Roles and functions are relatively well defined for masters, mates, and pilots on the traditional ship bridge. Although bridge-to-bridge radio communications have improved the coordination of vessel interactions, the lack of a formalized organizational structure for interdependent decision-making in ports and waterways creates opportunities for human error. Complicating factors are the rapid advent of new ship bridge configurations, navigation equipment, steering equipment, and integrated systems, all of which are beginning to appear aboard some new ships. The rapid evolution of advanced electronic navigation and piloting technology calls for new knowledge and skills, in turn increasing the need for continuing professional development, and perhaps for new organizational structures on ships. Acquiring the requisite skills can be especially difficult for marine pilots who are presently exposed to these new technologies on-the-job rather than through training programs.

Although advanced navigation and vessel control technology may provide improved means to navigate and maneuver in pilot waters, training in using a new technology often lags behind its introduction aboard ships. This weakness in training opportunities is especially true for many independent marine pilots who may not have occasion to use a new technology in their work or may use it too infrequently to ensure familiarity and proficiency. Since pilots may encounter an advanced technology for the first time while providing pilotage, it is important that entry-level and continuing professional development programs accommodate technological changes soon. These programs also need to continue to build and refine traditional skills that remain essential to piloting. Also needed are examinations of changes in organizational structures necessitated by these new technologies.

As navigators attempt to become familiar with advanced technologies on-the-job, there is the potential for *technology assisted* marine accidents. Such a phenomenon occurred in the form of *radar assisted* collisions in an earlier era. The potential for human error can be aggravated by the introduction of new technology and by bridge configurations that force the use of this technology before its reliability and accuracy are confirmed.

Summary Recommendations

Training programs should be developed concurrently with the introduction of new technology, and mariners should be trained in the use of this technology. These technologies should be carefully used in conjunction with traditional navigation methods to ascertain the new technology's suitability and reliability for application in pilotage waters. Mariners should also be apprised of changes in roles, functions, and organizations that can result from introduction of this technology. Pilotage authorities and marine pilot associations should make provisions to familiarize marine pilots with the capabilities and general use of new navigation technologies and with any new organizational forms that result. The Coast Guard should encourage the International Maritime Organization to adopt standard training procedures to facilitate the introduction of new navigation and piloting technologies into pilotage practices. The Coast Guard and the Maritime Administration should update prior assessments of marine simulation to determine the technology's capability and suitability for marine training and licensing. All pilotage authorities and marine pilot associations should consider the use of marine simulation as a means for improving pilot professional knowledge and skills, consistent with the current level of capabilities and instructional design.

MARINE PILOTAGE

Major Findings

Pilotage Practice

Marine pilotage in the United States has been the source of much controversy for many years. Although the operational performance of pilots is an important consideration, safety is sometimes a surrogate for economic issues that often underlie and stimulate controversy in pilotage. Particularly contentious issues are the form and manner of pilotage administration. Well-defined battle lines have been drawn between advocates of state and federal pilotage, yet there is no common reference for comparative analysis.

Effective piloting is essential for navigational and environmental safety. A pilot provides expert knowledge about ship behavior; local operating conditions; limitations of other traffic; and local procedures in the pilotage area for which the pilot is licensed, because a master's corresponding knowledge of these maneuvering factors is normally limited. The pilot normally directs and controls the vessel's maneuvering and is subject only to the overriding command authority of the master. When tugboats have to be used to assist with maneuvering, the pilot provides the necessary understanding of local operating practices and knowledge about tug performance and limitations. Traditionally, these services are provided by independent marine pilots, although in the United States the master or a mate aboard a U.S.-flag coastwise vessel may serve as pilot if licensed by the Coast Guard to do so.

Ship masters and senior mates serving permanently aboard the same vessel or sister vessels on regular routes can potentially achieve high levels of piloting expertise for their vessel over these specific routes. Under these select operating conditions, these individuals may be more familiar with the vessel's behavior than a marine pilot, although the pilot would have more extensive knowledge of local operating conditions. This must be balanced against shipping practices that over the past several decades have eroded the potential for masters and mates to acquire port-specific and vessel-specific pilotage expertise, except for on some coastwise vessels such as U.S.-flag tankers operating between U.S. ports. In order to reduce exposure to risk, some operating companies obtain marine pilots' services as an additional resource to enhance the overall safety of the passage even when officers aboard U.S.-flag ships are licensed to provide own-ship pilotage.

A combination of professional licensing, professional discipline, professional and official oversight, and responsiveness to vessel operator interests in reducing risk is necessary to achieve effective and efficient pilotage and full accountability to the pilotage profession, users of pilotage services, and the public. Yet, significant gaps exist in official accountability. These gaps are particularly ap parent with regard to docking, undocking, mooring, and intraport transits for some foreign trade ships in some localities. Furthermore, there is considerable variability with regard to the features and functioning of pilotage systems in different localities in the United States. Despite these gaps, however, pilotage in the United States is for the most part safe.

Formal requirements and informal professional development policies vary considerably for individuals providing pilotage services. Professional development of marine pilots holding only federal licenses and of docking masters is an individual responsibility, although development criteria often are established informally by associations or companies with which pilots are affiliated. The Coast Guard, as licensing authority, has not provided oversight or monitoring of professional development and performance; these functions are left to the discretion of operating companies. Accountability with respect to pilot performance has been achieved through Coast Guard disciplinary proceedings following marine accidents.

In most state pilotage jurisdictions, the professional development of marine pilots is the responsibility of pilot associations, although training and qualification requirements usually are set by a pilotage board or sometimes through legislation. Competence and proficiency are enhanced in varying degrees through selection, training, licensing, official discipline, and administrative organization.

The dual system of federal and state pilotage and pilot professional development programs are not designed or organized to ensure equivalent competence and proficiency within each pilotage area. In practice, however, marine pilots and docking masters who are members of pilot or docking master associations generally achieve equivalent expertise through the combined effect of pilotage administration, professional development, and operating practices.

There are no adequate data or methodologies for comparing safety performance for different pilotage functions, categories of pilots, or pilotage systems across localities. However, the committee found no compelling evidence to suggest wide disparities in safety performance among organized associations of marine pilots and docking masters. This finding also applies to those U.S.-flag ship's officers who possess a federal First Class Pilot's License or endorsement.

Pilotage Standards

There is an urgent need in pilotage for consistent application of high professional standards in every pilotage area as a defense against substantial variability in master and bridge team qualifications of foreign-flag ships. Although marine pilots, docking masters, and mooring masters typically provide effective pilotage services, there is considerable variability in the development of requisite skills and local knowledge. There is also considerable variability in the provision of professional and official oversight across all pilotage jurisdictions. It is possible for degraded piloting skills or other problems affecting individual performance to go unrecognized until an accident occurs. Nationally accepted guidelines or baseline standards are needed to guide and assist pilot associations and pilotage authorities in pilot selection, training, licensing, professional oversight, and professional and official discipline. Nationally accepted standards for the composition and accreditation of pilotage boards are also needed to assure that appropriate interests and subject matter expertise are represented. Notwithstanding the need for highly specific local requirements for pilot qualification and performance, a national approach to upgrading pilotage systems with respect to the central features of complete pilotage systems (see Chapter 3) is needed to provide a solid foundation for pilotage performance in each port and between ports. Such an approach can acknowledge, through establishment of an "own-ship" pilotage option for U.S.-flag ships only, that given certain operating conditions and individual experience levels, masters and experienced mates of U.S.-flag ships may be suitably qualified to pilot their vessels. Effective use of the own-ship pilotage option relies on both the vessel and the person piloting the vessel being directly subject to U.S.-flag-state authority and U.S. port-state control. This pilotage option would address both the public needs for safety and the economic concerns of operators of U.S.-flag ships.

Jurisdiction and Licensing

The division of pilotage jurisdiction in the United States is the product of the political and legislative processes. Although safety considerations are associated with decisions to require pilotage, jurisdiction is determined by a vessel's trade (domestic or foreign, based on cargo source and destination) rather than according to safety needs or the capability of governing authorities to satisfy them. State pilotage applies to all vessels in foreign trade. Federal pilotage administered by the Coast Guard applies to U.S.-flag vessels in domestic trade (referred to as "under enrollment") and can be applied to foreign trade vessels if a state does not exercise primary jurisdiction. As a result, there are substantial differences in pilotage requirements and administration, as well as duplication of staff and other costs. At the same time, the pilotage infrastructure has difficulty in adjusting to rapid change. This is the result of the long time required to build pilots' expertise, the limited access nature of port-level pilotage that constrains relocation of pilots to other pilotage jurisdictions, and the lack of other work that is suitable for pilots displaced by economic and technological changes in shipping.

The federal pilotage program has important features but lacks key elements that would make it a comprehensive pilotage system. Its important assets are its consistent nationwide organizational structure; basic, albeit minimal standards for licensing; approval processes for professional development programs designed to satisfy criteria for an original First Class Pilot's License; and a disciplinary process. But the federal program lacks quality assurance in training, particularly regarding the acquisition of skills prior to issuance of a Federal First Class Pilot's License or endorsement. As a result, these credentials are considered entry-level even by the Coast Guard, although the individuals holding these credentials often have considerable shipboard experience.

Most state-level pilotage systems are more complete and rigorous than the federal program in developing professional skills. Professional credibility of these programs is maintained through close association with experienced mariners and pilots. The programs provide rigorous assurance of strong initial professional competence, but most lack follow-through once a pilot is fully qualified. Nearly all pilots operating under the state system of pilotage are accountable to official governing authorities, although there are a small number of port areas where this is currently not the case. The effectiveness of official accountability in ensuring competent pilots, however, is uneven.

The composition of coastwise shipping that is subject to federal pilotage requirements has changed over the years. As the potential consequences of a single vessel accident have grown, the need for comprehensive pilotage coverage for commercial vessels has increased. Although such coverage can be provided through multiple pilotage systems such as the dual federal–state approach in the United States, the ability to ensure adequate and equivalent levels of piloting proficiency has not been demonstrated by the current practice. It would be more effective and efficient to rely on a single pilotage system in each port for ships following the concepts of the common European model, with route-specific and vessel-specific pilotage authorizations for suitably qualified masters and mates of U.S.-flag ships. Further, it is desirable to establish a backup means to correct shortcomings if a particular port-level pilotage system did not meet or did not maintain nationally accepted standards for pilotage systems or performance.

Pilotage administration in the United States needs to be improved, with the objective of providing for the consistent application of professional and system standards to ensure marine safety and environmental protection. The core of an improved system would involve:

- professional standards for all aspects of piloting and pilotage administration;
- administration of these standards through existing licensing and administrative bodies;
- consolidation of pilotage administration at the port or regional level in the manner prescribed in this report; and
- accreditation of port or regional pilotage systems.

Pilotage of Coastwise Tugs and Tows

Available data do not allow statistical evaluation of the effectiveness of pilotage for towing industry operations. The Coast Guard controls and adminis ters the pilotage requirements for coastwise towing vessels engaged in interstate commerce and applies these requirements consistently nationwide. However, the Coast Guard allows tug operators to "self-certify" their skills and then "serve as" pilots, without having a federal pilot's license or endorsement. The standards for self-certification do not provide reasonable assurance that the operator will have adequate knowledge and experience. Neither the Coast Guard nor any other entity officially determines or certifies that standards are met. Some operating companies implement high standards for their own personnel, but this is not universal practice.

Summary Recommendations

Standards

Nationally accepted professional and administrative standards and guidelines should be established without delay for all elements of existing pilotage systems. These elements include the professional development, licensing, and administration of pilots and pilotage with regard to pilot training, qualifications, pilotage boards, casualty investigation, discipline, and vessel pilotage requirements.

Jurisdiction and Licensing

The summary recommendations contained in this paragraph represent a consolidated approach that must be implemented concurrently to achieve the most effective remedy to needs in marine pilotage. An independent, multidisciplinary national commission on pilotage, navigation, and waterway safety should be established to guide and assist pilotage authorities and marine safety authorities in implementing systemic improvements with respect to professional standards, accreditation programs for marine pilotage, and system accountability. Action to establish a national commission could be initiated by the piloting profession, which should examine the feasibility of establishing accreditation processes and standards for professional development programs for pilots and docking masters. Such programs could in turn become the basis for establishing nationally accepted and applicable standards. The existing pilotage infrastructure should participate in the formation of the commission. In order to establish the broad credibility that would be needed to guide the pilotage system changes recommended by this report, the national commission should have a charter from the Congress. Specific goals and objectives should be established for the commission. Its membership must be designed to be capable of impartial and credible decision-making across the panoply of interests and must reflect policy and subject matter expertise. The commission should establish nationally accepted standards in consultation with representatives of federal, state, marine pilot, marine industry, and public interests. It should also develop accreditation procedures for marine pilotage and for vessel traffic services (discussed later). Periodic performance review should be conducted to ensure that goals and objectives for the commission are being met. The Department of Transportation, through the Coast Guard, should convene navigation and piloting safety advisory committees in each port complex or region if they are not already in place. These committees should provide expertise in support of marine traffic regulation by the Coast Guard and pilotage administration by pilotage authorities.

Pending development of nationally accepted standards for the piloting profession, all pilotage authorities should examine and improve their pilotage programs with respect to professional development, professional and official accountability, standards of the profession, and infrastructure. Action on the aforementioned recommendations should proceed without delay.

The pilotage recommendations in the following paragraph also represent a consolidated approach that must not be implemented separately. The order in which these recommendations are implemented is also important. The recommendations contained in the following paragraph should be implemented only after the preceding pilotage recommendations which address the essential elements necessary for an effective single marine pilotage system in the United States, are in place and functioning to expectations. This approach and implementation timing are necessary to ensure (1) harmony and fair treatment in the recommended approach, (2) comprehensive and consistent application of pilotage policy, and (3) the effective integration of all essential pilotage system features.

After a national commission is in place and functioning to expectations, and after universal standards of the profession, pilotage system accreditation, and port-level navigation and pilotage safety advisory committees are established, then a single marine pilotage system should be established for each port and waterway system. The system should be guided by national standards and accredited under procedures of the national commission but overseen locally by a nonfederal public organization with balanced membership representing the panoply of interests in pilotage. This organization should have authority to shape pilotage rules to meet regional and local needs. The system should include provisions for the master and mates of U.S.-flag ships to qualify for route-specific and vessel-specific pilotage credentials, federal or state, authorizing them to pilot the vessels on which they serve but making them subject to rigorous local requirements. Ultimately, the own-ship pilotage option should be consolidated under the single port area pilotage system and made subject to rigorous local standards, but it should be accredited to national criteria to ensure fair treatment. Independent marine pilots that hold only federal licenses should be brought into the port-level pilotage system as it is established. Federal requirements for a First Class Pilot's License or endorsement should be converted into a Coast Guard–administered national entry-level certification program that prospective marine pilots must satisfactorily complete as a prerequisite to further pilotage training.

Coastwise Tugs and Tows

Pilotage in the towing industry should be part of the fabric of the national port-level system. However, official oversight and administration should remain the responsibility of the Coast Guard. The Coast Guard should collect empirical data that are needed to assess the effectiveness and safety of navigation and piloting, with attention to pilotage in the towing industry. The Coast Guard should periodically use these data to evaluate program effectiveness. Administration and standards of pilotage for towing industry vessels should be strengthened with regard to individuals who by federal regulation may "act as" pilots without a pilot's license. The Coast Guard should establish and enforce procedures to ensure compliance with applicable requirements and standards. Standards that should be strengthened include the amount and recency of experience in the actual handling and navigation of towing vessels and barges under varying conditions and on specific routes. The towing industry should examine the feasibility of establishing an industry-sponsored, accredited training program as a means to ensure competence and proficiency of towing vessel operators.

WATERWAYS MANAGEMENT

Major Findings

Port-State Control

The volume of foreign-flag ships is of particular concern in improving safety performance, as there is growing evidence for some foreign-flag vessels of substandard conditions with respect to maintenance, bridge team composition and professional qualifications, and navigation and safety equipment. These conditions increase the risk to life, property, and the environment.

The United States does not oversee the construction or maintenance of foreign-flag ships or the qualifications and performance of their masters and bridge teams. Further, the United States lacks a large merchant marine that could be used to force change in foreign-flag merchant fleets through competitive forces. However, the construction, outfitting, and operation of foreign-flag vessels are strongly influenced by enforcement of international standards, insofar as these standards are incorporated into national laws. Unilateral measures, such as special construction or equipment requirements as a prerequisite for entry into U.S. waters, also are used to satisfy national interests in marine safety.

International efforts to counter substandard conditions rely on consultative relationships and enforcement of international protocols by flag-states and port states. The United States can enhance this effort by exercising its port-state prerogatives strongly, including use of new port-state authority for the inspection of crews that is being promulgated by the International Maritime Organization. The United States, through unilateral measures, can also profoundly influence change in ship structures (for example, by requirements for double hulls), material condition, and operating practices of foreign-flag vessels. Both the federal and state governments have a direct and compelling interest in the requirements for, and effectiveness of, the navigation and piloting of foreign-flag as well as U.S.-flag vessels in U.S. navigable waters.

Marine Traffic Regulation

Management of U.S. ports and waterways systems consists of overlapping and informally coordinated functions. The movement of a vessel is an independent action that is largely uncoordinated with other marine traffic operating in a particular area. Advisory committees, chartered locally or by the Department of Transportation, are available in a few ports, and they have provided for informal coordination and improved working relationships in terms of waterways management issues. No single organization has the responsibility for either coordinating vessel operations and movements to enhance safety or for improving efficiency within each port area.

A major benefit of VTS applications within the VTS service area—improvement in general order and predictability—is realized through the establishment of area-wide standard operating procedures and communications protocols. These features also help establish radio discipline.

The U.S. Coast Guard has substantial authority for marine traffic regulation, including time and space management and direction of specific actions by vessels, such as those carrying certain hazardous or dangerous cargoes. This authority is applied sparingly and selectively to promote safety, even where the Coast Guard operates VTS systems. Ensuring economic efficiency is not an agency mission.

A small number of East and West Coast marine pilot associations and at least one marine exchange also operate VTS systems or VTS-like services with voluntary participation. Some of these systems provide navigational information only, while others sometimes provide maneuvering assistance to association members (for pilot-operated systems) and occasionally to inbound or outbound vessels. Two pilot associations on the Gulf Coast coordinate the movement of large vessels under operating agreements with local maritime interests.

Although there are no national standards or protocols to guide VTS operations and administration, the Coast Guard conducts internal reviews of its VTS operation manuals and regulations to ensure consistency with the International Maritime Organization's VTS guidelines. However, the Coast Guard does not oversee, or set standards for, VTS systems or VTS-like services that it does not operate.

Bridge-to-bridge voice radio communications is widely acknowledged as a major factor in improving operational safety in ports and waterways. The intensive use of voice radio in VTS operations for communicating transit and traffic data between and among vessels and to and from a VTS is inefficient, except for the most important and perishable of information. Such use of voice radio introduces the potential for additional human error through information overloading of bridge teams and pilots, and it can potentially interfere with bridge-to-bridge communications initiated to resolve emergency situations. VTS–user interactions can be facilitated by adaptation of electronic data transmission technologies that provide essential information in a form conveniently used aboard each vessel. With adoption of such technology, a VTS system could serve more as a safety observer than as a traffic regulator, unless traffic management were required specifically as a routine VTS function or indicated by urgent circumstances.

Air traffic control is not analogous to marine traffic regulation; there are major differences in the operating environments. Yet, many features of the aviation model are adaptable to marine conditions. A national marine traffic regulation system could be established generally using the linked network concept found in the aviation sector. Introduction of most features that could be adapted from the National Airspace System would require the widespread introduction of new operating procedures and highly advanced technology, and are thus suited to international implementation to achieve universal application.

Summary Recommendations

Port-State Control

The Coast Guard should continue to augment its efforts to identify substandard vessels and take whatever action is necessary to enforce compliance with applicable international guidelines and U.S. requirements. Procedures should be established for reporting observed or suspected substandard conditions or inadequately crewed vessels that pose unacceptable operating risks. Provisions should be made to improve cooperation among the U.S. coastal states and the federal government in reducing risks that involve foreign-flag shipping.

Marine Traffic Regulation

All VTS systems and VTS-like services (including vessel information systems) should be accredited to international and national operational and performance standards. A national commission on pilotage, navigation, and waterway safety should be responsible for developing and promulgating standards and for accreditation. Government-operated and privately operated VTS systems and

VTS-like services should be expanded and improved to reduce operational and environmental risk. This effort should be promoted by the Department of Transportation. VTS operations should extend seaward of pilot boarding areas, where feasible, to guard against navigation and operational errors when approaching piloting waters.

The Coast Guard should operate VTS systems where these systems are used as the means to execute or enforce federal marine traffic regulation. All privately operated VTS systems and VTS-like services should be authorized by the Department of Transportation. The Coast Guard should establish or authorize a national training course for VTS instructors and an entry-level course for VTS personnel.

The Coast Guard, Army Corps of Engineers, and local advisory bodies should participate in determining special operational criteria for proposed vessel operations that present significant operational, environmental, or public health risks. The Coast Guard should assess the application of interactive electronic data transfer in VTS operations to reduce reliance on voice radio for information transfer and to improve VTS–user interactions and onboard interpretation of traffic information. This assessment should be coordinated with the Maritime Administration, the Federal Communications Commission, Army Corps of Engineers, and the Radio Technical Commission for Maritime Services.

NAVIGATION AND PILOTING TECHNOLOGY

Major Findings

Introduction of New Technology and Performance Criteria

Innovations in navigation technology hold significant potential for reducing operational risk and improving safety performance. However, significant impediments exist that constrain full beneficial application of emerging high-technology navigation systems. The structure and process for introducing and using new technologies need to be modernized rapidly to accommodate improvements in operational capabilities.

Electronic charting systems are rapidly being introduced for marine use and will be an essential part of integrated bridge systems. Electronic charting systems have the potential to improve navigational safety and to significantly reduce operational risk through the accurate and instantaneous display of a vessel's position. Electronic charting systems that consist of at least an electronic chart and real-time position data, and which meet legal requirements for navigation, could achieve universal commercial use following the examples of radar and very high frequency radio, although international action may be required for this to occur. Electronic Chart Display and Information Systems (ECDIS) will have the essential features to achieve real-time position-keeping benefits and by international and national definition be considered equivalent to paper charts for use in navigation.

Although some advances in operating practices and technology can be introduced by operating companies and professional associations, there are few obvious economic incentives for doing so. Furthermore, the existing marine navigation and piloting system does not facilitate the introduction and use of new technologies. The operating practices, laws, regulations, and legal precedents that form the organizational structure in which change occurs are based principally on older practices and technologies. This structure evolved; it was not designed nor is it well suited to foster or support the introduction of new and innovative approaches and technologies. Further, new technologies are being developed faster than are the technical and performance standards needed to guide and facilitate their use.

The introduction of new technologies likely will be uncoordinated unless systematically guided at the international level through technical and performance criteria. It will be complicated by competitive factors and operating practices. Technology introduction will also be complicated by existing institutional and legal requirements for use of traditional charts and navigation practices. The existence of numerous manufacturers will result in a proliferation of electronic charting systems that may or may not meet ECDIS standards and configurations. Such equipment, when introduced into the world's merchant fleets, will complicate greatly the efforts of marine pilots to familiarize themselves with, much less operate, these systems. Marine pilots may have to rely to a much greater extent on the watch officer to set up and manipulate the display. This situation may reduce safety, especially if there are language difficulties.

The full prospective benefits of the new technologies, especially ECDIS, are not likely to be gained in the near term unless deliberate measures are taken to promote the introduction of these technologies. Such measures must include establishment of technical and operating standards, as well as professional training for those that will be expected to utilize fully the systems' capabilities.

Pilots are expected to work safely and efficiently with shipboard navigation equipment that reflects the full spectrum of available technologies. Marine pilots can play an important role in the introduction and use of today's advanced navigation technologies by becoming familiar with and validating their capabilities for application in piloting waters. As new systems are developed, the demands on pilots increase. It is therefore desirable to put all ships on an equal technological "footing," at least in U.S. pilotage waters. This can be accomplished by onboard installation of suitable technologies that meet appropriate performance objectives, by developing hand-carried systems for use by pilots, or by a combination of the two approaches.

Hydrographic and Topographic Data

Tide, current, and weather information are not available in real-time except in select locations, nor have techniques been perfected for sensing changes in marine weather conditions. Tide and current prediction tables often are derived from survey data that are decades old. Hydrographic data for much of the nation's coastal waters were collected using single-position measurements of depth (i.e., lead-line soundings) rather than modern marine surveying equipment that provides comprehensive bottom profiles. The result is that chart data are substantially less precise than are modern electronic positioning systems.

Shipboard updating of charts is done manually using the changes published weekly by the Coast Guard and by the U.S. Army Corps of Engineers for inland waterway systems. Publication of updated charts by the National Oceanic and Atmospheric Administration is constrained by a substantial backlog of discrepancies, and there are no guidelines for setting priorities for making these corrections. Digital formats and procedures are available for preparing digital data for use with electronic charts, but digitizing the full chart portfolio will take 5-10 years at present resource levels. The legal status of electronic charting systems has not been resolved and may impede their wide-scale introduction.

Positioning Systems

A combination of Differential Global Positioning System (DGPS) technology and electronic charting systems appears to be the best available technical means for enhancing safety. This technology can provide instantaneous and accurate positions, steering guidance, automatic hazard warnings, and a permanent navigation record. ECDIS holds considerable potential for adding to this capability. Improved accuracy and reliability of Automatic Radar Plotting Aid (ARPA) functions is possible though integration with automated periodic broadcasts of position, course, and speed by individual ships, referred to as automatic dependent surveillance (ADS). However, DGPS is not completely implemented. As previously observed, adoption of electronic charting systems is likely to occur rapidly. However, universal adoption of combined systems that incorporate DGPS, ECDIS, ARPA, and ADS is not an immediate prospect.

Integrated Bridge and Control Systems

Effective use of an integrated bridge consistent with the practice of good seamanship may reduce operational risk. It consolidates the navigation, steering, lookout, and communications functions at one workstation, as is done in aviation. The traditional allocation of tasks and the nature of their interrelationships in the functioning of a traditional ship bridge seem straightforward, but the processes are complex, human-resource intensive, and can be error inducing. The way these tasks are assigned leads to a dependence on voice communication and reliance on others to share functional responsibilities. Each of these factors provides opportunities for error to occur. This is offset to some extent by monitoring and cross-checking that has evolved as a practice of good seamanship. Integrated bridge and control systems replace human-resource–intensive tasks with a system requiring fewer operators—in the extreme, only one. However, the new bridge also requires new operating skills. Monitoring and cross-checking must be accomplished through technological means to offset the potential for "single-person error."

The integrated bridge has proved effective where (1) the person directing and controlling the vessel has expert knowledge of the system and the ship, (2) frequently pilots the ship on a route for which the individual is qualified as a pilot, and (3) a full bridge team is present. The suitability of one-person bridges for large ships operating in pilotage waters has yet to be proven. How an independent marine pilot would interface with this new bridge system is not certain. Full use of the system's capabilities seems to require either the integration of independent marine pilots into the bridge team, a nontraditional role, or a redefined working relationship between the pilot and the individual operating the integrated bridge.

Integrated control systems may serve to reduce human error in the performance of many navigation tasks, as well as provide the means to reduce crew size. As automation decreases opportunities for hands-on experience, additional training may be required for the operators, so they can determine when integrated systems are not performing within tolerances. Training may also be required to build skills for taking corrective action. While reduced crew size may be satisfactory for operations on the open sea, decrements in already small bridge teams reduce the onboard resources for use in traditional navigation tasks, including hand steering. Hand steering is especially important, because when maneuvering, it may be more effective under certain operating conditions for the pilot or master to give rudder commands to a helmsman than to indicate a course to steer by autopilot.

Traditional Aids to Navigation

Navigators continue to rely heavily on traditional short-range aids to navigation, principally buoys and ranges. The usefulness of these aids often is compromised when most needed, that is, during heavy sea conditions and low visibility. The problem is being addressed by Coast Guard efforts to improve visibility of these aids and to advance the development and use of DGPS. There is little effort to develop electronic ranges that are similar in concept to the localizer systems that are used in aviation for approaches to airports.

Traditional aids to navigation will continue to play a central role for the foreseeable future, particularly for pilots. While the degree of reliance on these aids depends on the operating environment, pilots will find them essential, as points of comparison, for determining the reliability of advanced navigation systems in piloting waters. Visual and lighted ranges will continue to be particularly important in restricted waters; enhancements to improve the ability of mariners to discern ranges are needed.

Summary Recommendations

Introduction of New Technology

The Coast Guard should strongly encourage the development and updating of international technical and performance criteria and corresponding national standards and criteria for advanced navigation systems. This is needed to provide a solid foundation for the systematic introduction of these new systems. The Coast Guard should evaluate empirically the impact of advanced electronic positioning systems, automated steering systems, and integrated bridge and ship control systems on marine safety, piloting practices, use of traditional aids to navigation, and organizational forms and practices that may be required for safe navigation in the future. The Coast Guard and the Maritime Administration should encourage the development and enhancement of integrated navigation systems. These two agencies, the National Oceanic and Atmospheric Administration, and the Army Corps of Engineers should also examine and encourage development of improved environmental information systems as well as chart updating and correction systems.

Institutional Considerations

Laws and regulations addressing operational requirements for navigation and piloting technology should be based on performance objectives rather than equipment-based criteria, so the full operational benefit of the technologies can be obtained and innovative research and development are not inadvertently constrained. The Coast Guard and the Maritime Administration should continue research to identify technical and operating standards for new navigation and piloting technologies. These agencies should be joined by the National Oceanic and Atmospheric Administration and the Army Corps of Engineers in reviewing laws, regulations, and policies that are impediments to the introduction and effective use of promising navigation and piloting technologies. The agencies should modify policies and regulations under their jurisdictions to remove impediments and should recommend to Congress any changes necessary in enabling legislation.

Hydrographic and Topographic Data

The National Ocean Survey should improve its capability to conduct surveys with modern equipment in all U.S. ports, waterways, and port approaches. The Department of Commerce should fund this effort at a level that would remedy current shortcomings in hydrographic and topographic data that inhibit the full implementation of electronic navigation systems. The National Oceanic and Atmospheric Administration should accelerate efforts to digitize these data for producing electronic nautical charts and should lead an effort to resolve the legal status of electronic charts provided by either the agency or vendors using agency data.

Positioning Systems

The introduction of electronic charting and precision navigation systems suitable as onboard aids to enhance navigation safety should occur as soon as practical, consistent with the applications for which this technology is appropriate and with the development of the supporting infrastructure that is necessary to enable its effective use. Training should be provided concurrently with the introduction of the technology, as discussed earlier. The Department of Defense should establish fully the Global Positioning System (GPS) at the earliest opportunity, and the Coast Guard should accelerate establishment of DGPS. The Department of Defense and the Department of Transportation should develop a long-term operating and maintenance plan for GPS to ensure its continued availability once it is fully established.

Traditional Aids to Navigation

The Coast Guard should maintain and enhance shore-range aids to navigation that support traditional and evolving navigation technologies and should continue efforts to improve visual and electronic acquisition of buoys during unfavorable operating conditions. The feasibility of electronic ranges and distance-measuring equipment for specialized local use should be examined.

MARITIME RESEARCH AND DEVELOPMENT

Major Findings

The substantial and rapid changes in ship and navigation technologies, manning, and operating practices have created uncertainties about the performance of virtually all systems in marine transportation. The available research literature is limited and primarily focuses on ship construction and technology.

The Coast Guard's applied technology research is current with technologi cal developments, but there has been little practical improvement in safety data except to make the agency's existing marine data bases internally compatible. Although human error is a major factor in accidents, very little research is available on maritime human systems and safety performance. The studies that do exist are often based on data not designed to answer questions about human performance. The Coast Guard's vastly improved data collection program for human causes of marine accidents is ongoing, but the availability of human systems data to support empirical analysis is at least several years in the future. Pioneering work in human systems that used marine simulation, that was sponsored by the Maritime Administration and the Coast Guard, has become outdated in the absence of dedicated, continuing research to identify trends and assess their effects and implications. At the same time, operation of the Maritime Administration's Computer Aided Operations Research Facility has been privatized, resulting in a change in focus from fundamental research to training and applied research. There also have been severe reductions in the agency's research funds. The overall result is that research pertaining to the organizational structure and culture of marine transportation is very limited.

Summary Recommendations

A program of dedicated fundamental research is needed to address marine systems safety, waterways management, navigation and piloting technology, port-state versus flag-state policy, navigation and piloting practice, and human systems. Such a program would generate great benefits in terms of marine safety and economic efficiency. The research needs are substantial and, as they span the missions of the Coast Guard, the Maritime Administration, the National Oceanic and Atmospheric Administration, Army Corps of Engineers, and the National Transportation Safety Board, a comprehensive cooperative research program is recommended. In view of the Department of Transportation's responsibilities for marine safety, and the research capabilities of its agencies and their ongoing navigation technology research programs, an appropriate agency from the department should coordinate federally-sponsored marine navigation and piloting research.

1

The Marine Navigation and Piloting System

SUMMARY

Marine navigation and piloting form a complex operating system consisting of vessel and waterway systems; human operators; organizational culture and structure; and a supporting infrastructure for management, pilotage, policy and regulation, and professional development. System effectiveness depends heavily on human performance. Risk varies according to physical factors such as waterway dimensions; vessel factors including size and loading; economic factors; transit considerations; potential consequences of marine accidents; and human factors. Navigation and piloting practices and processes have strong roots in tradition; they evolved to support independent vessel operations and to guide safe interaction between two vessels. The organizational structure for decision-making involving more than two vessels or on a port-wide basis is loosely integrated and mostly informal. Waterways management functions are spread among various government and commercial organizations. Marine traffic regulation is applied sparingly, but interest in this approach is growing. Technology already exists that could be used to better integrate and improve waterways management; an example is port-wide marine traffic regulation using vessel traffic services. Some management changes are warranted in part because physical improvements to channels are not timely, and few waterways are managed or regulated to conform to their designed capacity. Channels are stressed routinely beyond designed safety margins, usually with only a cursory assessment of risk that does not always include consultation with port safety officials.

Operating trends have reduced the opportunities for many masters and deck officers aboard all categories of oceangoing ships to acquire hands-on ma

neuvering experience with their vessels in shallow water conditions. At the same time, navigation and in-port workloads have increased the potential for fatigue and stress. Some masters may have limited opportunity to oversee pilot performance, a command responsibility. English language words are used for maneuvering commands during the piloting of foreign-flag ships in U.S. ports and waterways while a marine pilot is aboard. However, the lack of a universal operating language can impede joint passage planning by the master of a foreign-flag ship and local pilots. Some foreign-flag ships are operating with reduced crew sizes, affecting bridge team support to the pilot. These conditions put additional professional demands on, and increase the importance of, local pilots as they increasingly are being called on to act as a line of defense against substandard ships and crews.

International measures to improve commercial vessel safety seek to provide universal results, but they may not be employed fully or in a timely fashion by all maritime countries. The United States is involved in so much maritime trade that actions taken to enforce provisions of international treaties applicable to foreign-flag ships operating in U.S. navigable waters (referred to as port-state control) can be effective in ensuring that applicable technical as well as operational standards are met. Unilateral action by the United States can potentially be used to force international technical as well as operational standards to a higher level. Unilaterally imposed standards (such as double hulls required by the Oil Pollution Act of 1990 for tankers) would be conditions for the entry of foreign-flag ships to U.S. ports and, as such, would influence that portion of the world fleet trading with the United States. Unilateral measures that impose more rigorous requirements than international standards, but remain within their overall context, can potentially encourage similar changes to the standards. However, unilateral action is usually taken solely on behalf of national interests and may or may not receive the necessary international support that would be necessary to raise international standards to higher levels.

The current understanding of operational risk is insufficient to guide improvements in the marine navigation and piloting system. Despite its many shortfalls, the system works most of the time. But when marine accidents occur, close examination of navigation and piloting practices is sure to follow.

INTRODUCTION

The *marine navigation and piloting system* is a large-scale sociotechnical system comprised of several subsystems: navigation and piloting tasks, technology, human systems,[1] and organizational cultures and structures. These sub

[1] Human systems are large-scale systems comprised of people interacting with each other, usually in geographically dispersed settings. Decision-making in such systems is highly interdependent, with

systems exist and interact within an operating environment supported by vessel and waterway systems, and characterized by substantial risk and recent changes (Figure 1-1). Problems that can lead to failures in the marine navigation and piloting system can arise in any single element of the system, or in combinations of these elements. Consequently, the system can best be understood by examining not only its individual components, but also their interdependencies and interfaces: for instance, among the people, technology, and the tasks; or among

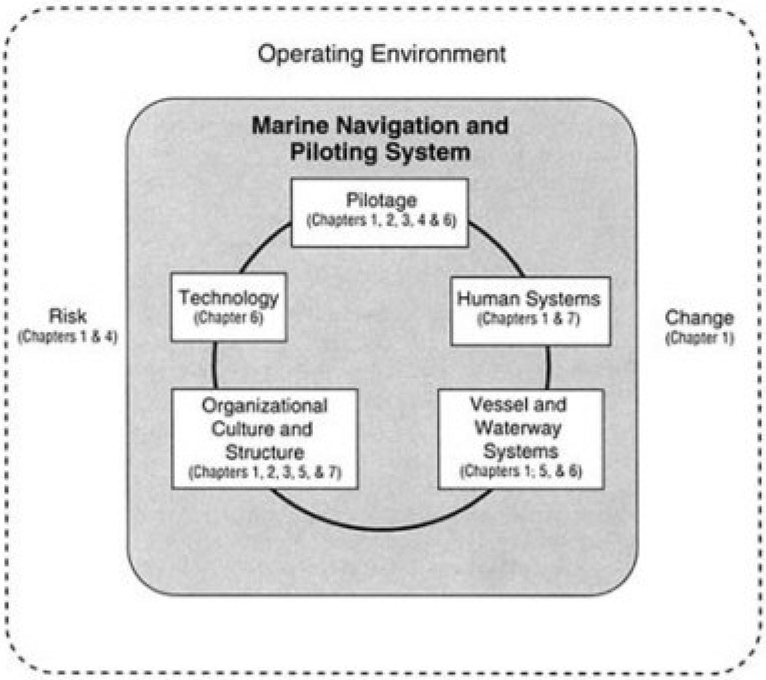

FIGURE 1-1 Main components of the marine navigation and piloting system and report chapters in which they are principally addressed.

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actions and decisions in one subsystem producing effects, intended and unintended, in other subsystems. In the context of marine navigation and piloting, subsystems of large-scale human systems include ship bridge-to-shore, bridge team, master-pilot, bridge-to-bridge, and vessel-port control interactions, among others. Of interest in these systems are the decision-making, organizational behavior, organizational culture, communications, training, selection, retention, and qualification processes. In contrast, *human factors* is the area of ergonomics that focuses on human-machine interfaces.

the tasks, people, and prevailing organizational cultures. By examining the system's essential elements and their relationships, this approach recognizes that a "fix" in one part of the system may, in fact, cause difficulties and even dysfunctions in some of its other parts. Effective planning, operations, management, administration, and research in the marine navigation and piloting system requires such a system-level approach.

The chapter first describes pilotage (see Box 1-1 for pilotage terms used in

BOX 1-1 PILOTAGE TERMS USED IN THIS REPORT

Pilotage: The provision or conduct of pilot services. Pilotage also is used to denote the fee structure for pilot services.

Pilot (generic): A person with expert local knowledge of the pilotage route and superior shiphandling skills. Either directs and controls the maneuvering of the vessel in pilot waters subject to the overriding command authority of the master or provides advice to the master for this purpose. The pilot is normally an independent pilot (self-employed private contractor) or a master or deck officer who holds a pilot's license or endorsement for specific routes.

Pilot (under U.S. and state laws and regulations): For U.S.-flag ships in the domestic trade, the pilot must be licensed. The pilot may be an independent pilot, Federal First Class Pilot, or a member of the vessel's regular complement holding a Federal First Class Pilot's License or endorsement.

For ships in foreign trades, including U.S.-flag ships, pilotage varies by jurisdiction. Primary jurisdiction rests with the states. If a state has exercised jurisdiction, a state-licensed pilot is required for some or all of a route. If a state has not exercised jurisdiction, the Coast Guard has enabling authority to require a federally-licensed pilot. Not all waters have pilotage requirements. Where no pilotage requirements exist and a pilot is taken, the pilot usually holds a state pilot's license, federal pilot's license, or both; the pilot would not be operating under the terms of that license when providing services.

For domestic coastal towing industry vessels, the person piloting the vessel must hold a Federal First Class Pilot's License or endorsement for tank barges over 10,000 gross tons or may "act as pilot" under the authority of an operator's license for self-propelled vessels of not more than 1,600 gross tons or tank barges of not more than 10,000 gross tons.

There is no federal pilotage requirement for inland towing industry vessels; the term pilot is informally applied to a specific company employee attached to the vessel as a member of the crew, other than the captain, who alternates with the captain in piloting the vessel over selected routes. States are not empowered to exercise pilotage jurisdiction in the domestic trade.

Piloting: Directing and controlling the maneuvering of a vessel.

this report), the environment within which the marine navigation and piloting system operates, and the difficulties that changes in this environment have generated. The primary elements of the system then are discussed and assessed: piloting tasks, vessel and waterways systems, technology, and organizational structures and cultures. Developments and trends that are expected to influence marine navigation and piloting over the next decade are identified as is the continuing controversy over pilotage, establishing the context in which this re

Marine Pilot: An individual who operates from an organized pilot association or group and is licensed by a governing authority (federal, state, or local authority empowered by a state) to provide pilotage services over specific waters or routes. May provide some or a combination of bar, harbor, river, and docking pilotage services.

Federal Pilot/Federally-Licensed Pilot: An individual holding a Federal First Class Pilot's License or First Class Pilot's endorsement on a merchant mariner's document or vessel operator's license.

State Pilot/State-Licensed Pilot: A marine pilot licensed by a state. May or may not hold a Federal First Class Pilot's License or endorsement depending on state requirements and pilot association policy, but virtually all do.

Bar Pilot/Sea Pilot: A marine pilot who pilots a vessel to and from the pilot grounds and through the entrance (over the bar) to a harbor or estuary.

Docking Master: An individual who specializes in docking and undocking ships. Sometimes also transports vessels within the port complex between berths or berths and anchorages. May or may not hold a Federal First Class Pilot's License or endorsement (required for piloting vessels in domestic trade), but most do. Formerly, docking masters were tugboat captains who boarded vessels to control tugboat assistance. Most are now organized into associations affiliated with tugboat companies. Docking masters operate in most East coast ports. Sometimes referred to as a docking pilot.

Harbor Pilot: A marine pilot who provides pilotage services within a port complex. Typically docks and undocks vessels where docking pilots are not used for this service.

River Pilot: A marine pilot who pilots a vessel in a river operating environment. Typically docks and undocks vessels where docking pilots are not used for this service.

Mooring Master: A person specializing in mooring vessels to offshore facilities. Typically a shore-based employee of the company operating the vessel or platform.

Shore-based Pilotage: Pilot provision of maneuvering advice or orders from a site external to the vessel being provided pilotage services.

port advice will be applied. Building on this foundation, the report discusses the ability of the system to conduct planning, operations, management, administration, and research activities, and implications of those findings.

PILOTAGE

Since the early days of marine navigation, vessels entering or leaving port, or navigating other hazardous waters, have been guided by pilots possessing a thorough knowledge of local currents, tides, rocks, shoals, weather, and other conditions. The skill and care of the pilot are vitally important for the safe passage of vessels, for the safety of lives and cargo, and as means to protect the port and the marine environment. Today, as in the past, vessels normally are required by maritime countries to engage independent marine pilots when entering or leaving ports or piloting waters.

Piloting demands more than guiding a passage through a particular waterway; it requires a diverse mix of navigation and shiphandling skills (Armstrong,

Modern car carrier westbound in Chesapeake and Delaware (C & D) Canal. Car carrier superstructures have large wind catch areas. Wind effects must be compensated for during transits. Additional tug assistance may be required for some maneuvering evolutions in restricted shallow waters. (Wendy Mitman Clarke, *Soundings*)

1980; Hofstee, 1991; MacElrevey, 1988; Plummer, 1966). In practice, a pilot serves as an expert advisor to the vessel's basic navigation complement and performs navigation and piloting functions. The pilot determines when and where to turn, as well as when and how to execute the necessary maneuvers. The pilot also provides a traffic management function by coordinating traffic queues, horizontal separation between vessels, and arrangements for meeting and overtaking other traffic.

Pilots are also responsible for maneuvering different types of ships with different degrees of maneuverability. Considerable skill is needed to compensate for variations in vessel behavior, even between sister ships. Variations in maneuverability result from factors such as differences in hull form, propulsion and steering equipment responsiveness, and loading. Pilot skills include the ability to anticipate and respond to the varying intensities of vessel reactions, particularly with regard to the effects of shallow water and small under-keel clearances (Armstrong, 1980; Gates, 1989; Hooyer, 1983; MacElrevey, 1988; Plummer, 1966; Reid, 1986).

Although a ship's captain is always responsible for safe navigation of the vessel (with few exceptions, such as the Panama Canal, where responsibility for navigation devolves to the Panama Canal pilot [MacElrevey, 1988; Parks, 1982]), ship navigation in piloting waters depends increasingly on the attentiveness and skills of marine pilots (Armstrong, 1980; Cahill, 1983, 1985; MacElrevey, 1988; Meurn, 1990). Where pilotage is compulsory, a marine pilot normally has immediate charge of a vessel's navigation. In ports where pilotage is not mandated and marine pilots have a reputation for competence and proficiency, similar levels of control normally are exercised (Armstrong, 1980; Cahill, 1985; MacElrevey, 1988; Meurn, 1990; Nautical Institute, 1991a; Parks, 1982). Thus, in simple terms, as the vessel nears or operates in a port, navigation decisions rely on the expert knowledge of the pilot. In the absence of an independent marine pilot, a ship's officer would perform the same functions, but would usually lack an equivalent level of familiarity with local operating conditions. Automated piloting expert systems (that is, artificial intelligence decision aids) are under development, ostensibly to supplement but not to supplant piloting expertise (Grabowski and Sanborn, 1992; Grabowski and Wallace, 1993).

In the United States, responsibility for regulating pilotage for vessels in foreign and coastwise trades is shared between federal and state authorities. Pilotage for vessels operating solely on inland waters is not regulated *per se*, although some inland passenger vessels are required to have federally-licensed pilots under current manning laws (46 U.S.C. 8101) and regulations.

Insuring that pilots are competent in their trade is a complex challenge for governing authorities, pilot associations, and operating companies. To compound the challenge, applicants for pilot's licenses arrive with many different levels of nautical experience. They may be graduates of maritime schools, ship masters, ships' officers, ferry operators, tug masters or mates, or veterans of Navy or

Coast Guard service. Some have no prior maritime experience at all. Although the International Maritime Organization (IMO) has published recommendations concerning the minimum knowledge, skills, and procedures that should be required of maritime pilots (Hofstee, 1991; IMO, 1981), there is no national or universal pilotage model for the development and administration of pilotage programs (Herberger et al., 1991; Japanese Pilot's Association, 1990). Pilot training and licensing requirements vary widely. Approaches for developing or assuring theoretical knowledge, expert local area knowledge, and shiphandling and piloting skills range from written examinations to on-the-job training to comprehensive theoretical and practical skill development programs. Training, licensing, and regulation of federally and state-licensed pilots are addressed in Chapters 2 and 3.

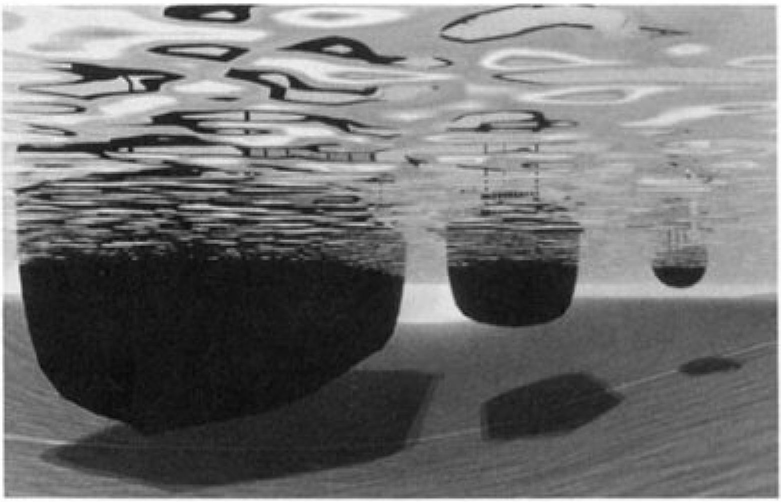
VESSEL AND WATERWAY SYSTEMS

Vessel and waterway systems are basic elements in the marine navigation and piloting system, without which the system would not function. These systems interact when vessels arrive, depart, or transit a port area. *Vessel systems* are comprised of steering and propulsion systems, traditional navigation equipment (such as charts, magnetic and gyro compasses, and bridge wing gyro repeaters), radio navigation aids, and collision avoidance aids, and advanced electronic positioning technologies. Such advanced systems may include satellite navigation systems or integrated bridges, which may employ expert system decision aids to integrate navigation, positioning, communications, and vessel operation information. Expert systems may also provide recommendations on vessel steering, operations, or communications.

Waterway systems are comprised of natural and man-made navigation channels, as well as aids to navigation which are installed in the channels. Traditional aids to navigation such as lights and buoys, radio navigation systems, and vessel traffic services (VTS) are included, as are newer systems such as interactive electronic lights and buoys, and advanced vessel traffic advisory and management systems.

Port and Waterway Design and Operation

Some ports are more constrained than others by channel limitations. Overall, existing ports and waterways do not always accommodate ships that are most modern in terms of efficiency, safety, and sometimes cargo-handling capabilities, even though shipowners and port and waterway managers are under economic pressure to use large, sophisticated ships at the maximum possible draft. The latest ships maximize the amount of cargo that can be carried; ports that can accommodate them can gain or maintain a competitive advantage. As a result, waterway design limits routinely are challenged by operating practices (Gates, 1989; NRC, 1985, 1992a). In such cases, a marine pilot frequently plays a critical role for the shipowner or operating company in estimating whether a vessel that exceeds design criteria can transit the pilotage route safely.



The evolution of hull size from sailing ship through 1950s tanker to modern tankship. The size of modern ships often exceeds the design criteria that were used to plan and construct many existing channels. (*U.S. Army Engineer Waterways Experiment Station*)

Determining whether vessels meet or exceed design criteria can be accomplished without fear of accident using computer-based and physical scale-model shiphandling simulations. For example, tanker transits to and from Valdez, Alaska, were simulated in 1976, before oil shipments began, and several times thereafter, leading to establishment of transit lanes and ship-assist tug needs (Jones, 1980; Williams et al., 1982). However, such advance preparation is not standard practice (NRC, 1992a). It is much more common to find that answers to these questions result from an informal system that depends on the experience, expertise, and judgment of pilots, usually with the aid of extra tugs and under the most favorable operating conditions. Ship owners and pilots could consult with knowledgeable naval architects or waterway designers in assessing a waterway's capability to support safe navigation (Gates, 1989), but there is little evidence that such consultations occur. Nonbinding guidelines could be developed to aid the decision-making process. Such guidelines could be designed to provide flexibility for decision-making to accommodate the highly situational nature of each passage and pilot knowledge and skills. No written, nonbinding guidelines were found, although there are unwritten guidelines that are handed down as part of the pilotage tradition through apprenticeships.

Once a port or waterway project is constructed, there are typically no requirements for assessing its overall effectiveness, its adequacy for vessels that exceed original design parameters, or effects of changes in bathymetry or geometry on vessel behavior beyond that required for maintenance dredging. One exception is the Army Corps of Engineers' practice of applying established study procedures for port and waterway improvements to determine, for example, where channel deepening is justified economically because of changed operating practices (NRC, 1985, 1992a). Except in canals and lock systems operated by the Corps of Engineers, neither federal agencies nor local project sponsors regulate or manage the passage of vessels that exceed the vessel size and maneuvering criteria that were used for channel design (NRC, 1983, 1985, 1992a; US-ACE, 1980). The Coast Guard occasionally imposes transit restrictions, usually for ships carrying dangerous cargoes in bulk or during periods of heavy commercial fishing or recreational activity. But as a general rule, independent marine pilots by default often become the final arbiters of port and waterway design limits, with or without the benefit of engineering information or the results of simulation experiments to help guide decision-making.

Waterways Management

Operation, maintenance, and regulation of the marine navigation and piloting system in the United States, loosely defined as *waterways management*, is the responsibility of a variety of organizations, each with differing objectives, operating authorities, and resources. There is no single manager or overall authority in the United States that integrates all of the elements of the marine navigation and piloting system. Responsibility for coordinating or controlling vessel operations, scheduling, and navigation support activities is distributed among various parties, including the U.S. Coast Guard, U.S. Army Corps of Engineers, port authorities, marine pilots, marine exchanges, port and pilot commissions, private companies, and other organizations (NAS, 1980; NRC, 1983, 1992a). Waterway system components are not organized into national, regional, or even local networks. Some components may be part of a national program, as is the case with aids to navigation. However, basic responsibility for vessel operations remains aboard the vessel with its master, and individual vessel operations are rarely coordinated across a port area.

Responsibility for information acquisition, and interdependent decision-making based on that information, is distributed among individuals dispersed throughout the system, ashore and afloat, in an operating environment that is constantly changing (NRC, 1990a,b). Although coordination of vessel sailing orders and pilot dispatching often is practiced on a company- or association-wide basis, there is no formal organizational structure for decision-making to guide the operation of the vessels while in pilotage waters, except where vessel traffic services have been established (described later in this chapter and in Chapter 5).

A locale-specific, informal structure is typical in interactions between independent pilots. But, in practice, *the independent decisions that are made aboard each vessel have far-reaching implications and effects that are not always fully recognized or accommodated elsewhere within the affected port, waterway, or river system*.

Because no single authority manages or coordinates marine traffic, approaches to waterways management vary widely across the nation among operating companies, port authorities, and organizations with safety responsibilities. Even the administration of generic components of national programs may vary in the absence or insufficiency of national standards, performance criteria and measures, performance monitoring, and coordinated program upgrades.

Substantial technology exists that could be used to improve waterways management, particularly with regard to traffic management and regulation. For example, automated, computer-based data management and electronic communications systems are in widespread use for cargo; these technologies could also be employed to assist in traffic management. A few VTS systems share vessel information electronically across national boundaries, and use this information with varying degrees of success for queuing traffic. Some VTS systems, marine exchanges, and port authorities collect and distribute vessel arrival and departure data (Herberger et al., 1991). However, the systematic integration of data about vessel movements, and coordination of that data, remains a primitive practice throughout the United States and in many ports internationally.

Marine Traffic Regulation

Traffic control, as applied in aviation, is not used in marine transportation. However, extensive traffic regulation authority is available to the U.S. Coast Guard such as Title 33, Code of Federal Regulations, Part 6 and the Port and Waterways Safety Act of 1972. Some of these authorities, including anchorage and pilotage regulations, are exercised routinely. Others are used only occasionally. Traffic control measures are imposed only in specific situations, such as transits of ships carrying liquified natural gas in bulk, major marine recreational or sporting events, temporary obstructions to navigation, or "dead-ship" movements in constricted channels (that is, a vessel being moved within a harbor by tugs while its propulsion system is not functioning). Traffic control measures used in these situations typically consist of specific restrictions on vessel movements, such as transits during daylight hours, tug escorts or management of the time and space in which the movements will occur.

Vessel Traffic Services (VTS)

Vessel traffic services and VTS-like systems such as ship information services are operated by either government or private parties in about 20 locations in the United States (see Chapter 5). The primary VTS role, as presently employed worldwide, is to provide information and advice about vessel movement rather than maneuvering orders, although traffic is managed routinely for certain waters under prescribed conditions by some Coast Guard-operated VTS centers (Ives et al., 1992; Koburger, 1986; Young, 1994). For example, one-way traffic is prescribed for any tankship of 75,000 deadweight tons or greater transiting Rosario Strait in the state of Washington's San Juan Islands (PSVTS, 1987). One-way traffic also is required for tanker traffic in Valdez Narrows. Additionally, some VTS centers intervene selectively under the authority available to and policies of the cognizant Coast Guard Captain of the Port and VTS director to influence the outcome of prospective vessel interactions. There are no definitive national guidelines for such intervention (Ives et al., 1992).

By contrast, the Army Corps of Engineers pursues more traffic management that is active. The agency operates and maintains general navigation features along approximately 25,000 miles of shallow and deep-draft waterways and at 235 locks at 191 sites in the continental United States. Scheduled operation and maintenance activities (including dredging) that affect navigation are announced to the public in *Notices to Navigation Interests*. Emergency closures of waterways or locks are coordinated with the Coast Guard and the marine industry.[2] Lockmasters coordinate traffic through the lock systems, a growing number of which are sharing vessel arrival and departure information through electronic data systems.

Authority to control international and interstate commerce is reserved for the federal government, except for marine pilotage of vessels engaged in foreign trade, which has been returned to the states. However, states may impose certain rules on matters not regulated by Congress in order to meet environmental, safety, and other objectives. For example, the state of Washington has imposed escort requirements for large tankers operating in the San Juan Islands area. Tug escorts were mandated by the Governor of Alaska for tanker transits to and from Valdez following the *Exxon Valdez* accident (escorts had been provided by agreement since opening of the pipeline terminal in 1977).

Direction of ship maneuvers is possible from shore. Such direction generally has been accomplished by independent marine pilots providing maneuvering instructions from shore stations (referred to as shore-based pilotage). Such services occasionally are provided in a few foreign ports, principally when adverse

[2] The term *marine industry*, as used in this report, includes shipping companies, towing industry companies with operations in ports and waterways in which ships operate, companies operating commercial passenger vessels, and the supporting industrial infrastructure including port authorities. The term *marine community* is used more broadly. It includes the marine industry, marine pilots, pilotage administrators, federal agencies with missions and responsibilities associated with marine transportation, and government-operated ferry services.

weather does not permit the boarding of a pilot in the normal pilot boarding area and usually in cooperation with a VTS. In Rotterdam, under conditions of reduced visibility, marine pilots sometimes work with the port's VTS to guide movements of vessels that have marine pilots aboard (Herberger et al., 1991; Ives et al., 1992).

Voluntary traffic management (queue management) services are provided for the Sabine waterways and the Calcasieu Ship Channel by local state pilot associations. Pilot associations also provide small-scale VTS information services for the entrances to the Delaware Bay, Chesapeake Bay, and Southwest Pass in Louisiana and for Los Angeles and Long Beach harbors. A few vessel traffic centers—including those for the Coast Guard VTS in New York, the Canadian Coast Guard VTS in Vancouver, British Columbia, and the pilot-operated VTS in Long Beach—routinely provide marine pilots with navigation support for precision anchorage. In the case of VTS New York, such support also is provided to tug operators (Ives et al., 1992). Beyond these services, however, there is little interest within the maritime community in moving toward an aviation-like traffic control system, although there may be potential benefits in doing so (Chapter 5).

Traffic Control Issues

Government-operated shore-based traffic systems traditionally have been perceived as a challenge to the command responsibility of the vessel master to navigate safely and to the role of marine pilots in providing expert piloting and shiphandling services (Hofstee, 1990a; Ives, 1991; Ives et al., 1992; NAS, 1980). Furthermore, the capability of shore-based personnel other than licensed pilots to actively control traffic is seriously questioned (Hofstee, 1990a; Ives, 1991). Also questioned is the ability of the Coast Guard to provide qualified VTS personnel, although good performance results are reported for some Coast Guard-operated VTS systems (Ives et al., 1992; Young, 1992, 1994). However, in the aftermath of the *Exxon Valdez* accident, a more cooperative spirit has emerged within the maritime community. Mariners also are becoming more supportive of wider application of VTS (CCG, 1992). Many marine pilots express concern about a perceived general decline in bridge team proficiency (and in some cases, the absence of a bridge team altogether), a proliferation of electronic equipment without standardized formats, and inadequate maintenance of critical navigation systems. Each of these conditions increases the pressure on marine pilots. Highly publicized accidents involving tankers and passenger vessels, as well as the trend toward unlimited liability for pollution events, also have helped foster the apparent increase in receptivity to safety alternatives such as VTS. Mariners are adamant, however, that such alternatives should be used to complement rather than to replace traditional navigation and piloting practices.

Port-State Versus Flag-State Control

U.S. ports and waterways are vital links in national, regional, and local intermodal transportation and economic systems. About one-third of domestic intercity trade and almost all foreign trade by weight pass through the system each year (NRC, 1992a). The flow of cargoes through U.S. ports reached 2.2 billion tons in 1989 (MARAD, 1991). Considering the shrinking oceangoing U.S.-flag fleet, which now numbers fewer than 400 ships, the heavy traffic indicates that the United States is becoming a nation of port operators rather than one of ship operators. Today, the nation's maritime power lies in its status as an economic superpower with a large volume of seaborne trade; its relative importance as a flag state has declined while that as a port-state has risen. On one hand, there has been a dissipation in the nation's power to use its merchant fleet to directly influence foreign-flag vessels by setting a standard for them to follow. On the other hand, national action to enforce provisions of international treaties applicable to foreign-flag ships operating in another country's navigable waters (referred to as port-state control) can be effective in ensuring that applicable technical as well as operational standards are met. Port-state control measures can be a very powerful tool—if exercised.

The United States has had a very active port-state control program for many years, and has extended the inspections to include provisions of various international treaties such as the 1973 International Convention for the Prevention of Pollution from Ships (referred to as MARPOL). Another example is the current U.S. Control Verification for Passenger Vessels program. All foreign passenger ships operating from U.S. ports must pass stringent quarterly examinations and drills. Furthermore, the IMO is working to expand authorized port-state control measures to include the qualifications of ships' personnel (IMO News, 1993; OSIR, 1993d, 1994).

International conventions or treaties, including associated standards and guidelines, are adopted nationally through domestic legislation. A ship failing to comply with national legislation and implementing regulations may be barred from entering port. If in port, such as ship may be barred from sailing, either under the terms of a treaty or convention or by a specific national law or regulation. The United States can also apply these measures to U.S.-flag vessels in fulfillment of its responsibilities as a flag state. Because shipping companies respond to profit and loss, imposed delays are a powerful, if indirect, influence on operating practices.

Unilateral action is sometimes taken when international, port-state, and flag-state measures do not result in an acceptable level of safety and a country determines that additional measures are necessary for the protection of its marine interests. Unilateral measures that impose more rigorous requirements than international standards, but remain within their overall context, can potentially encourage similar changes to international standards. However, unilateral action is usually taken solely on behalf of national interests and may or may not receive the necessary international support that would be necessary to raise international standards to higher levels. Unilateral action has not been used extensively, but has been used by the United States. Notably, Congress enacted the Oil Pollution Act of 1990 (OPA 90) (P.L. 101-380) which imposes double hull requirements for tankers trading with the United States.

Unilateral action by the United States can have far-reaching effects. But legislation and regulations do not always fully consider, or even identify, possible secondary effects or difficulties that might result from implementation of marine safety protocols. The Coast Guard prefers to work through international maritime forums such as the IMO and the International Association of Lighthouse Authorities (IALA) to seek cooperative improvements (Harrald et al., 1991b; Porter, 1994). However, the Coast Guard has also announced that it will take aggressive port-state action to compensate for weak flag-state performance in providing for safe ships and competent officers and crews (Fairplay, 1992a; Kime, 1992). The Coast Guard indicated to the committee that its efforts to work through international forums has been complicated by unilateral legislative actions taken by Congress and U.S. coastal states, although state jurisdiction is limited.

Professional qualifications of captains and bridge teams are guided by the IMO Standards for Training, Certification, and Watchkeeping (referred to as the STCW) (IMO, 1978, 1991), but these requirements are the responsibility of national licensing administrations. Some authorities believe the STCW guidelines were weakened to obtain the concurrence of flag states whose economic interests outweigh concerns for safety. Representatives of the European Community (EC) and the United States have alleged that certain flag states permit operation of substandard ships and crews (Fairplay, 1992a; Harrald et al., 1991a, 1991b; OSIR, 1993d; Peters, 1993; Porter, 1989; Salvarani, 1992; Ugland, 1993). The Coast Guard has stated it will no longer tolerate such ships entering U.S. waters (Fairplay, 1992a; Kime, 1992).

If U.S. safety initiatives become more rigorous than standards elsewhere, then better ships might be dispatched to U.S. ports while substandard vessels are diverted to ports where less-stringent regulations prevail. Thus, universal improvements would depend on involvement by other port-states—a factor motivating the Coast Guard to work through the IMO, classification societies, and other consultative bodies and associations. Nevertheless, improvements in U.S. standards potentially can lead to corresponding improvements in international standards and operating practices. As a consequence of the *Exxon Valdez* accident in 1989, and more recently the loss of the *Aegean Sea* in Spain and the *Braer* in the Shetland Islands, international support has been growing for increased port-state control. In the meantime, marine pilots are being called upon to detect substandard conditions as quasi-public officials responsible to their licensing authorities, the Coast Guard, or state officials, and at the same time, to continue to serve ships under traditional master—pilot relationships.

Economic Versus Social Regulation

Government regulation of societal activities is of two distinct types: economic regulation and social regulation. While all regulation is essentially in the public interest in the sense that it affects the overall welfare of society, there are substantial differences between the two types of regulation. The two types constantly are mixed together in assessments of pilotage, complicating resolution of important safety and performance issues.

Economic regulation is driven by the perceived need to assist the market to achieve optimum allocation of resources. Its focus is on markets, prices, entry and exit conditions, and the legal obligations of suppliers and buyers; in other words, who may charge what prices to whom, for what services, where, and when (Abrahamsson, 1982). Such regulation in pilotage affects the setting of fees, the formation and operation of pilot associations, and the control of entrants into the profession.

Social regulation, on the other hand, is prompted by concerns for safety, health, and environmental protection. As such, it is focused on the *conditions* under which a service provider, such as the pilot, discharges his or her duties. Examples with respect to pilotage are licensing requirements; training and evaluation procedures, including how and to what level pilots are trained and evaluated; prescribed operational procedures such as use of VTS; reporting requirements; and accountability issues. Social regulation usually involves the regulatory agency in rather detailed facets of operations, thus restricting the service provider's freedom to act and make decisions. In this sense, the regulatory agency (or government) becomes a major force in the determination of both service and cost levels—that is, social regulation has a substantial economic impact (Abrahamsson, 1982). While this report recognizes economic regulation and impacts, it focuses on issues in the domain of social regulation.

HUMAN SYSTEMS

The safety performance of the marine navigation and piloting system depends on effective human performance. In the maritime sector, the factors that greatly influence human proficiency and performance are organizational cultures and structures, professional development, and applications of technology. This section introduces the human operators and some of the difficulties faced in professional development and performance. Human systems are examined in more detail in Chapter 7.

Navigation and shiphandling skills, judgment, and decision-making capabilities of individuals involved in piloting a vessel are critical and fundamental. The person operating or piloting a vessel is expected to function effectively under all operating conditions and contingencies and be prepared for any emergency. Such expertise traditionally is developed and maintained through formal instruction and training, observation, tutelage, and trial and error. However, insight gained through experience does not appear to be shared systematically among masters, mates, marine pilots, and vessel operators. The nature of marine operations keeps these individuals dispersed throughout the marine navigation and piloting system and relatively isolated from their colleagues. Furthermore, there are few convenient means to systematically share information and lessons from operational experience.

Shiphandling Skills

Mariners often assert that shiphandling in narrow channels is more an art form than a science and that something akin to intuition is required to detect and balance the dynamic, yet often subtle, interactive forces acting on a vessel so as to maintain control over its movement (Armstrong, 1980; Gates, 1989; Hooyer, 1983; Plummer, 1966). Modern ships tax even the best shiphandler's skills because:

- waterway improvements lag years behind changes in ship design and performance (NRC, 1992a);
- ship propulsion and steering systems may be designed for at sea efficiency rather than maneuvering performance (Gates, 1989);
- the general maneuvering behavior of ships in narrow channels and shallow water is known, but actual behavior is uncertain, especially where under-keel clearances are only a few feet (Gates, 1989; Graff, 1993; Plummer, 1966);
- determinations of natural changes in channel geometry are not always timely or conveniently available to vessel operators and pilots (Gates, 1989); and
- real-time data on environmental conditions including weather, currents, and tide and river stages are lacking.

In addition, opportunities for a ship's officer to develop practical shiphandling skills are limited by shipboard organization, manning practices, functional responsibilities of deck officers while in piloting waters, and fatigue (such as might result from a rapid series of port calls to discharge and pick up freight cargoes between transoceanic voyages). In practice, therefore, shiphandling skills are developed principally through observation of pilotage, apprenticeships, on-the-job training, or a combination of these approaches. In this manner, individuals accumulate the experience needed to handle the variability in vessel behavior as influenced by channel geometry, loading, propulsion and steering systems, vessel traffic, and environmental conditions. Crisis situations requiring instinctive decision-making and emergency shiphandling are seldom observed aboard ship. Usually, the first occasion for practice arises when the mariner is faced with a real-life emergency. There is no evidence that advance preparation for emergency shiphandling is offered on a broad scale.

Shiphandling simulation training using a manned-model. Manned-model facilities are located in France (shown in picture), England, and Poland. The U.S. Navy's manned-model facility in Little Creek, Virginia, at which some merchant mariners participated in training during Naval Reserve duty, was closed in 1993 as a budget austerity measure. (*SOGREAH Port Revel Centre*)

Use of simulators to provide experience in basic and port-specific shiphandling is growing but is still far from universal (Crooks and Douwsma, 1989; Guest, 1992a,b; Marine Institute and IMD, 1993). Emergency scenarios sometimes are included in this training. Marine simulation has not evolved into a standard element of piloting apprenticeships, although manned-model and computer-based shiphandling simulations increasingly are used to support continuing professional development in many pilot associations. Both generic and route-specific simulations have been used; in one case, training simulations led to substantial modifications in standard operating practices. In this case, tanker transit speeds in northwestern Washington State waters were reduced in order to improve the potential effectiveness of tug escort response in the event of loss of a tanker's steering or propulsion (William Bock, Puget Sound Pilots, personal communication, October 7, 1991). Use of computer-based simulations also is growing slowly in basic training for the towing industry (Sanborn, 1991).

Masters

Shipboard organization still maintains its naval form, with the captain the head of the pyramid; this is viewed as necessary for effective command and control in a sometimes hostile operating environment (Cahill, 1985). The com mand role of the master is well-established in admiralty and pilotage law, which confirm the master's overriding authority while his vessel is under the direction and control of a pilot for navigation (Cahill, 1985; MacElrevey, 1988; Meurn, 1990; Parks, 1982). Traditionally, masters are considered to have the most knowledge of any individual regarding their own ship's maneuvering behavior. Masters regularly assigned to the same vessel can observe its maneuvering characteristics over a wide range of loading and operating conditions. Some masters also handle their vessels in piloting waters and during docking evolutions.

Computer-based ship bridge simulator featuring modern instrumentation, steering consoles, and conventional and ARPA radars. Ship bridge simulators with full bridge mock-ups and instrumentation, and a 180 degrees or greater continuous field of view are located at Castine, Maine; Buzzards Bay, Massachusetts; Newport, Rhode Island; New London, Connecticut; Kings Point and New York City (2), New York; Linthicum Heights and Piney Point, Maryland; Dania, Florida; Toledo, Ohio; San Diego, California; and Seattle, Washington. (*STAR Center Dania, Florida, American Maritime Officers*)

Expert skills for handling the vessel can be developed by masters handling their own vessels in pilotage waters. Masters and sometimes senior mates with such expertise may, in the pilotage jurisdictions of some countries, obtain exemptions from the requirement to take an independent pilot. The individual receiving the exemption virtually always must be a citizen of the country in which the ship is registered, and the ship must be operating in that country's waters.[3] Not taking an independent pilot may reduce pilotage costs. Thus, ship

[3] In Europe, the exemption option is applied somewhat more broadly to include ships flying the flag of an EC member country and masters and mates licensed by these countries.

ping companies may have some interest in continuing this practice. Where such programs exist, qualification criteria are generally rigorous to ensure that the master (or mate) has a level of expert local knowledge equivalent to that of independent pilots insofar as this expertise would be applied to the vessel (or vessels of near identical design and performance characteristics) being piloted. Qualification criteria usually include a prescribed number of round trips on the pilotage route for which the exemption would be granted, a written and practical examination, and certification by the pilotage authorities (Herberger et al., 1991). The United States does not follow the model of pilotage exemptions for masters. However, U.S. federal pilotage requirements principally result in masters and deck officers piloting U.S.-flag ships in coastwise trade, rather than by independent marine pilots, although the use of marine pilots for even these vessels is growing, as discussed in Chapters 2 and 3.

Despite these opportunities for masters to acquire pilotage, there are indications that the capability of masters in general to assure the safety of their ships is being eroded, although a few operating companies have implemented rigorous training programs to counter this trend in their fleets (Beetham, 1989, 1990; Cahill, 1985; Intertanko, 1990; Nautical Institute, 1991c; Peters, 1993). For example, the opportunity for a master to maneuver his or her vessel is limited by reliance on pilotage services, assignments to different vessels, unfamiliarity with the operating environment, and the few opportunities to engage in coastwise trade with frequent port calls. Master reliance on pilots also tends to increase as a result of personal fatigue from conditions experienced during the voyage, or from in-port workloads. The degree to which safety performance is affected by these factors is not certain. Resolution of these issues and identification of countermeasures, if needed, will be important in ensuring marine safety.

Although masters of U.S.-flag ships face challenges similar to those confronting their international counterparts, shiphandling does not stand out as a problem. Generally, U.S. masters have reputations as good shiphandlers. Most remaining U.S. ship (tanker and freight) operating companies have made substantial efforts to secure masters who are well suited personally and professionally for their jobs. Professional development is monitored and special training sometimes is provided. Well-defined operating procedures are available for some companies, and considerable effort also has gone into providing masters with effective bridge teams (Chevron Shipping Company, 1988; S. J. Jones, American President Lines, personal communication, November 9, 1993).

Deck Officers

Deck officers have little opportunity to gain practical shiphandling skills aboard ship, in the U.S. merchant marine or elsewhere. The same factors that limit master opportunities to gain shiphandling skills also apply to mates. Further, the shrinking size of the oceangoing U.S. fleet without a corresponding decrease in the pool of deck officers limits opportunities for sea service (Phillips and Weintraub, 1993). This also affects the opportunities for practical shiphandling training of cadets at the nation's maritime academies, the source of most new deck officers. There are limited opportunities for cadets to receive hands-on shiphandling training, either aboard school ships or while on training assigned aboard merchant ships. These opportunities are augmented to some extent at most of the maritime academies by computer-based shiphandling simulation training. On graduation, a cadet is expected to have a conceptual understanding of shiphandling. The maritime academy infrastructure for developing third mates and assistant engineers (Figure 1-2) was established when the U.S. merchant fleet was larger, and it cannot adjust quickly to swings in demand for junior officers. Today, about 70 percent of maritime academy graduates are placed in afloat positions, albeit not all aboard seagoing ships (Figure 1-3). There is a reported shortage of skilled mariners internationally, but competitive factors constrain the opportunities for U.S. mariners to serve aboard foreign-flag ships. Mariners from traditional maritime nations are expensive relative to mariners from lesser developed nations (Intertanko, 1990).

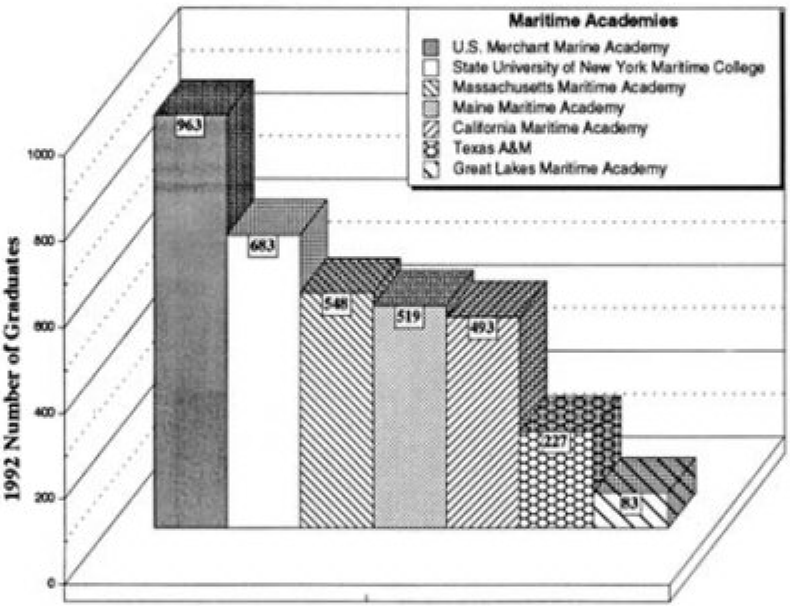


FIGURE 1-2 Undergraduate enrollment at the federal and state maritime academies, November 1992 (MARAD, unpublished data).

Hands-on opportunities to maneuver a ship, unless serving with a master

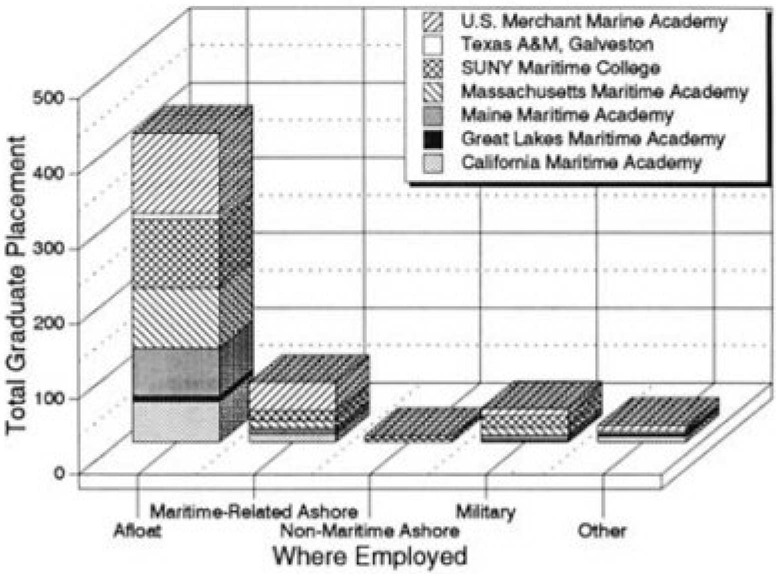


FIGURE 1-3 Employment data for Class of 1991 graduates of the federal and state maritime academies (MARAD, unpublished data).

BOX 1-2 THEORETICAL KNOWLEDGE

Nautical science theory and procedures for effective navigation, including the use of positioning equipment, are well established and work well for ocean and coastal voyages. They also provide the basic understanding necessary for shiphandling and piloting (Appleyard et al., 1988; Armstrong, 1980; Bowditch, 1981; Crenshaw, 1975; Fifield, 1980; Hooyer, 1983; MacElrevey, 1988; Maloney, 1985; Meurn, 1990; Plummer, 1966). Deck officers and marine pilots who served as deck officers acquire their theoretical knowledge in the classroom, usually early in their career. Such training is also given by a few marine pilot associations. But some marine pilot programs rely on apprenticeships, on-the-job training, and self study (at individual discretion) for acquisition of theoretical and local knowledge, as well as navigation and shiphandling skills. Deck officers who worked their way up though the ranks of the deck department and most towing industry operators are trained on-the-job, although some attend classroom training available through industry-sponsored schools. Tug-specific texts are available (Blank, 1989; Brady, 1967; Reid, 1986). Maritime academy graduates joining deck departments within the towing industry bring with them basic theoretical knowledge, but they require industry-specific indoctrination (David C. Buchannan, Maritrans, personal communication, May 29, 1991).

interested in the professional development of mates, usually occurs late in a career, many years after any classroom instruction in theory (Box 1-2). Manning practices also limit opportunities to gain maneuvering experience. Pre-arrival, cargo and docking duties, and deck watch schedules on arrival and departure reduce the opportunities for chief and second mates to observe or participate in shiphandling and piloting evolutions from the ship's bridge. These duties also are a source of fatigue and stress that can affect performance of navigation tasks. Mates typically function as members of a bridge team aboard U.S.-flag ships, and the mate on watch can observe maneuvers in piloting waters. However, mates rarely, if ever, have an opportunity to handle the ship in confined waters.

ARCO Independence, a U.S.-flag very large crude carrier (VLCC), underway at sea. (Vince Streano, *ARCO Marine*)

Similar manning and operating practices prevail for foreign-flag ships. Additionally, for vessels with reduced manning, there may be no flag-state requirement for a full watch team, although unilateral requirements might be imposed by a port-state as a condition of entry. Manning practices for junior deck officers usually mean little continuity with individual vessels, so it is difficult to establish a consistent frame of reference for building shiphandling knowledge.

Bridge Team Support

Concern has been expressed internationally over a possible shortage of qualified deck officers by the next decade (Herberger et al., 1991; Irvine, 1993; Ugland, 1993). There is already a trend toward drawing on nonmaritime labor pools to reduce labor costs. Data are not available to confirm or refute reports by marine pilots that this trend is fueling a general decline in the overall level of qualifications among deck officers. Marine pilots also report that, aboard many ships in international trade, there is no such thing as a fully functioning bridge team: only the master and a helmsman[4] may be present.

Sometimes the master of a foreign-flag ship cannot lend full support to passage planning or safe navigation, due either to fatigue or to difficulty in communicating with the pilot because of the lack of a common language. This is in stark contrast to conditions in years past when, according to many marine pilots, someone on the bridge usually had good command of English, often a deck officer. Now pilots report greater difficulty in communicating with bridge personnel because of language problems. The evidence suggests that marine pilots are capable of conning a ship safely using commands that traditionally consist of English language words; however, considerable effort is sometimes required to guard against misunderstanding and alternative wording must sometimes be used. Difficulties can arise when it becomes necessary to communicate in greater detail than can be accommodated through basic conning commands and the limited and variable vocabulary of English language words of some masters and mates. No common language has been adopted, either for communications among the pilot and the bridge team or for communications between a foreign-flag vessel and a vessel traffic service. "Sea Speak," a special purpose, stylized vocabulary based on English is available but is neither mandatory nor in universal use (IMO, 1985b; Weeks, 1988, 1989; Weeks et al., 1979, 1984). However, there are indications that marine education and training programs of some countries are moving toward greater emphasis than before on instruction in English (see Kelly, 1990).

Again, no organization, including marine pilot associations, was found to be collecting data that could be used to validate these observations or gauge the scope of these problems. Nevertheless, the aforementioned anecdotal reports and the operational experience of committee members suggest that, at least for some ships, limits on the knowledge of the master and deck officers regarding a ves

[4] A qualified helmsman is essential when manual steering is required. Helmsmen are generally taught on-the-job, although there are exceptions. For example, helmsman training is provided by the Seafarers International Union for its members using computer-based simulation and training vessels at a union-operated facility. Also, ARCO Marine has implemented a computer-based simulation training program in which each tanker's full bridge team, including helmsmen, is scheduled to participate.

sel's behavior, and on their shiphandling and piloting proficiency, may significantly restrict the support they can provide to the pilot.

TECHNOLOGY

Navigation technology has advanced spectacularly over the past several decades. Bridge-to-bridge radio communication capabilities and radar are in near-universal application aboard commercial vessels and ferries. These features, along with gyroscopic and magnetic compasses, constitute the basic suite of navigation equipment aboard virtually every ship calling at U.S. ports. Many tugboats also are equipped with gyro compasses. Electronic positioning equipment is available on most oceangoing ships and many tugs. Most ships are also required to have automatic radar-based collision avoidance systems. These are referred to as automatic radar plotting aids (ARPA). The advent of "bright face" (that is, daylight) digital radar displays has eliminated the need for the hood that was essential for daylight use of analog radar; thus, a pilot or bridge team member can refer to the radar picture without losing visual bearing.

Integrated electronic bridge systems are being introduced, incorporating electronic charting systems, radar, Differential Global Positioning System (DGPS) capabilities, autopilots, collision avoidance software, and propulsion and steering system monitors. Expert systems (that is, artificial intelligence systems) for piloting are under development as are international performance standards for Electronic Chart Display and Information Systems (ECDIS). The *ECDIS* designation will be applied to electronic charting systems that meet these standards, which will establish legal equivalency to paper charts.

Despite the availability of advanced technology, basic technology dominates aboard the world's merchant fleets (see Box 1-3). Furthermore, marine navigation and piloting remain heavily dependent on effective performance by human operators—masters; vessel officers and bridge teams; marine pilots; and in some port complexes, shore-based navigation support personnel. This continuing reliance on human performance is significant, because marine safety authorities and many safety reports and studies have attributed up to 80 percent or more of marine casualties to human error in some form. Understanding why human error occurs is essential in determining the potential of technology to improve human performance (Lucas, 1992; Moore et al., 1993; NAS, 1981; Reason, 1990, 1992). The degree to which human performance can be supplemented, or human operators replaced by technology, especially in navigation and piloting, is controversial.

The introduction of technology can alleviate some problems while creating others (NRC, 1990b, 1991a). For example, one ship with a fully integrated bridge system and an advanced steering system, while on its first transit of an East coast pilot route, took a sheer across the channel in good weather and grounded. The vessel's automated helmsman feature was in use. The actual cause of the ground ing is not certain, but the use of automated features on an initial transit of a channel raises some interesting issues. Because the ship was relatively new, on its maiden voyage to the area, and equipped with innovative navigation and steering technology, the marine pilots that provided piloting services were not familiar with the ship's specific maneuvering behavior in narrow channels and shallow water, and with the capabilities and effectiveness of its automated systems. The ship's specific behavior relative to the channel's hydrography and prevailing operating conditions had not been observed previously.

BOX 1-3 GENERAL ASSESSMENT OF TECHNOLOGY USEFULNESS AND AVAILABILITY

According to data developed through correspondence with a representative sample of U.S. shipping companies, pilot associations, and a few towing industry companies, traditional navigation technology is most important in current navigation and piloting practices. High-technology systems are neither as available nor as familiar to masters, mates, pilots, and vessel operators. The utility and availability of technology as reported by correspondents is ranked from most available and useful (shown in bold type) to least available or useful (shown in italics) in the following list. Mariner acceptance and use of high-technology navigation systems is likely to increase as emerging electronic navigation systems become more available aboard ships and tugs, as familiarity with their capabilities grows, and as trust and confidence in these systems is earned through enhanced operations.

Rudder angle indicator
Gyroscopic (gyro) compass and repeaters
Engine revolutions per minute (RPM) indicator
Aids to navigation: Lighted buoys
Radar
Very High Frequency (VHF) transceivers (installed)
VHF transceivers (handheld)
Standard nautical paper charts produced by the National Oceanic and Atmospheric Administration
Aids to navigation: Daymarks

The incident illustrates the importance of proving a system's effectiveness and building operator familiarity, trust, and confidence in system performance through operational experience (see Chapter 6). This approach was taken in the introduction of integrated bridge technology aboard large passenger ferries operating in the Baltic Sea. Use of computers to conduct maneuvers automatically was not attempted until there had been extensive operational experience; decisions on when to begin maneuvers remained with the master or a suitably qualified mate until the system was proven and trust in its performance established (Herberger et al., 1991).

Fathometer
Magnetic compass
Aids to navigation: Unlighted buoys
Aids to navigation: Lighted ranges
Aids to navigation: Other lighted shore aids
Voice broadcast of VTS information
Aids to navigation: Radar transponder beacons (RACON)
Doppler speed log
Rate-of-turn indicator
Automatic radar plotting aid (ARPA)
Visual tide gauges
Aids to navigation: Unlighted ranges
Anemometer
Bearing circle
Traffic signals
Cellular phone
Global Positioning System (GPS)
Aids to navigation: LORAN
Aids to navigation: Beacons/radio direction finders (RDF)
Fully integrated electronic bridge
Electronic chart and electronic chart systems
Differential Global Positioning System (DGPS)
Television broadcasts of navigational information
Omega
Source: Ramaswamy and Grabowski, 1992

Whether the state-of-the-art of maneuvering systems has advanced to the point where confidence and trust can be applied universally in actual operations is an open question. Currently, each new integrated bridge system must be proven aboard ship. While regularly assigned masters and navigation teams may become familiar with this equipment through its use, independent marine pilots who rely on operational experience and strict rotational assignment practices to build familiarity with varying equipment types and configurations could be placed at a severe disadvantage.

Familiarity with high-technology could be built through marine simulation, as demonstrated by the aviation model, although this is not common practice (Guest, 1992a,b). Ship bridge simulation facilities may have actual or simulated ARPA units for full-mission simulation. A number of maritime schools and training facilities have radar simulators that are used for radar observer certification courses required by the Coast Guard for marine licenses. Few training facilities, if any, have the latest-generation electronic charting systems, and thus, the facilities are not able to offer training in their use. Even if the equipment were available, assumptions about long-term retention and transfer of knowledge and skills developed during full-mission and part-task marine simulation training are based primarily on preliminary research (D'Amico et al., 1985; Hammell et al., 1985; O'Hara and Saxe, 1985) and on anecdotal reports. Performance of individuals following simulation training has not been tracked. Furthermore, lessons from human performance research in other sectors have not been routinely applied (see Elkind et al., 1990; NRC, 1988, 1991b, 1992b, 1993), although bridge resources management training has recently been adapted by a consortium of marine and aviation interest in Europe (Koning, 1993; Wahren, 1993).

ORGANIZATIONAL CULTURES AND STRUCTURES FOR DECISION-MAKING

The organizational structure for decision-making that affects vessel movements ranges from a well-defined, traditional naval command structure aboard the bridge of a ship (Box 1-4) to informal, loosely organized, and sometimes ad

BOX 1-4 SHIP MANAGEMENT PRACTICES FOR U.S.-FLAG SHIPS

Traditionally, the staffing of U.S.-flag ships included deck, radio, engineering, and stewards personnel. Radio officers have been removed from coastwise ships by an exemption available under the Federal Communications Act. Members of the deck department are responsible for vessel navigation, radio operations, cargo loading and discharge, and the maintenance and upkeep of deck equipment, anchors, lines, cargo, and navigation equipment, as well as fire fighting and lifeboat systems. Deck officers include a master (or captain), a chief mate (the chief cargo officer), a watchstanding second mate (the primary navigation officer), and one or two watchstanding third mates. Unlicensed deck crew members can include able-bodied seamen and ordinary seamen. The typical bridge team consists of three people: The watch officer, the helmsman, and a lookout (when required). However, under normal at sea navigation operations during daylight, there usually are no lookouts. A lookout is added when the ship is in restricted waters or port environs and at night and during periods of poor visibility. Sometimes during reduced visibility conditions a second lookout may be positioned at the bow. In restricted waters, the master or second licensed deck officer is required to be on the bridge. Additionally, a local marine pilot may board the vessel, either to provide advice to the master on navigating the local waters or to direct and control the vessel's movement (Chapters 2, 3, and 4). A marine pilot is generally not considered to be part of the bridge team, per se, although all bridge personnel must work effectively as a team. More formal integration of pilots into the bridge team is being attempted on a limited basis for some high-technology ships.

hoc procedures. The latter is common within most port and waterway complexes and river systems supporting ship traffic. Each self-propelled commercial vessel is a self-contained platform that is designed to operate independently of all other vessels. On each ship's bridge, the captain is always in command, and the person piloting the vessel is subordinate to command authority. While maneuvering orders are typically given by the pilot directly to a helmsman (or less commonly, given through the master or mate to a helmsman), a well-defined traditional role, the orders are made under the master's command authority.

The master may countermand these orders or pilot the vessel (referred to as "taking the conn") even if a pilot required by a pilotage authority for the waters traversed is aboard. Exercise of the command prerogative to countermand a pilot's orders rarely occurs and then only for cause; masters are expected to be capable of identifying obvious errors in piloting but often lack sufficient local knowledge to determine subtle deficiencies that may contribute to more serious maneuvering problems during a transit. A similar decision-making structure exists aboard smaller vessels such as tugboats, although the number of individuals in the pilothouse is usually less than aboard a large ship; pilots may or may not be required by regulation, but independent marine pilots are usually not taken.

The framework for interactions between two vessels meeting, crossing, or overtaking in a harbor or narrow channel is well defined. The International Rules for Preventing Collisions at Sea (COLREGS)—the nautical rules of the road—provide very precise rules that guide decision-making in these situations, even specifying whistle signals keyed to these rules. However, now that bridge-to-bridge radio communications are available aboard virtually all ships, towing industry vessels, and passenger vessels, any necessary arrangements for safe interactions normally are coordinated by radio. Whistle signals are still sometimes used in conjunction with radio calls, as a primary means of indicating intentions if radio communications have not been established, and to signal danger during emergency maneuvering situations. Interactions involving more than two vessels, a typical scenario for harbors or waterways, are more complicated; maneuvering arrangements are most easily coordinated by radio. In such cases, considered a special circumstance by the COLREGS, the precise rules give way to prudent seamanship and are followed only as is practical and prudent. Broad coordination or management of vessel traffic is not addressed in the COLREGS, although VTS participation requirements are addressed. The rules also provide general guidance on the use of traffic lanes and traffic separation schemes.

Beyond rules for the aforementioned interactions, there is little formal structure in most of the nation's port and waterway complexes and river systems to guide or assist in decision-making. Decisions made on one vessel may have implications not only for that vessel's transit but also for those of other vessels met minutes or hours later. A decision to speed up or slow down may result in an untimely meeting, such as between a large oceangoing ship and a tug with a 1,000-foot long barge flotilla at a difficult bend in the lower Mississippi River.

In another case that could affect a safe passage, a vessel may depart from a visually obstructed berth in a constricted waterway without knowledge of other vessel traffic already in the system.

The decision-making process for these situations is largely ad hoc. Although bridge-to-bridge radio communications have provided a much improved capability for communicating arrangements for interactions between vessels (USCG, 1972), the lack of a formalized organizational structure for interdependent decision-making in ports and waterways creates opportunities for human error. For example, vessels may make radio broadcasts "in the blind" as a general form of alert to other vessels. Whether the pilot or bridge team aboard vessels needing this information actually hear the call is left to chance. In other cases, the process is more structured. Through their dispatch service, pilots are generally aware of the movements of other vessels with pilots aboard. By the same means, operators of harbor craft may have general knowledge of their company's fleet movements. However, the decision-making structure is, in general, so informal in most ports that a causal observer might wonder whether the system works. That it works most of the time is attributed to the skills and abilities of most commercial mariners coupled with a port operating environment that is somewhat forgiving in comparison to aviation; the combined effect generally provides the margin necessary to recognize problems in time to take corrective action. However, some maneuvers in confined waterways require precision timing in their execution and have little or no margin of safety if an error is made (see Chapters 4 and 5).

The safe passage of ships in ports and waterways is aided by the use of local experts, the marine pilots. Marine pilots are the first representatives of port-state interests to board an inbound vessel. As such, they have the first opportunity to observe some aspects of the fitness of the vessel and its bridge team for entry into local waters. Although decision-making affecting vessel transits is mostly informal and independent, there is an interdependent aspect to the process. Marine pilots generally operate in one of the most structured subsystems within the marine navigation and piloting system. Most work in a tightly knit community of professionals providing like services. They become familiar with the capabilities and piloting strategies of their colleagues through continued service on their pilotage routes. By either advance notice from pilot dispatchers, or through voice recognition from radio transmissions, they often know which colleagues are piloting other ships, and they generally know how their fellow pilots will respond in multiple-vessel maneuvering situations. Such knowledge becomes critical, for example, when ship interactions in close quarters can be accomplished safely only by causing the hydrodynamic forces generated by the movement of each vessel to interact, as in meetings in the Houston Ship Channel (see Chapter 4; Gates, 1989; Graff, 1993; NTSB, 1989a; Plummer, 1966). Preparation for this particular interaction is rigorous so that the pilots can precisely coordinate their maneuvering orders.

Sometimes, however, the professional capabilities, judgment, responsibility, accountability, and organizational or working relationships of captains, marine pilots, mates, and docking and mooring masters have been inadequate, as demonstrated by the nature and frequency of human error in marine accidents. Failures in performance are not entirely the fault of the mariners, but are inherent in the informal organizational structure and decision-making processes of the overall system (Perrow, 1984; Reason, 1992). For this reason, there is growing interest, nationally and internationally, in ways to boost human performance through improvements in waterways management, as well as in professional development and oversight.

RISK AND CHANGE IN THE MARINE NAVIGATION AND PILOTING SYSTEM

Assessing Risk

Modern risk assessment methodologies calculate risk as the algebraic product of the probability of an adverse event occurring during a defined period and the cost that would be incurred if the event took place. For economic risk, cost equals the economic cost. For other types of risk, other cost measures can be used; for example, environmental risk assessments use environmental cost. The resulting product serves as a measure that can be compared numerically with risk in other sectors to gauge whether the level of risk is acceptable.

This form of risk assessment is rarely applied to guide commercial marine operations. Assessments that have been conducted are generally proprietary and are related to operating company liability and insurance; such assessments are not available to safety authorities for use in planning waterway improvements or for performing marine safety assessments. Even if they were, no guidelines exist for what level of risk is acceptable for use in planning waterway improvements (NRC, 1992a). Similarly, the regulation of marine traffic by port-level marine safety authorities has not been guided by statistically valid risk assessments although the Coast Guard has applied statistical measures in assessing the need for VTS systems (Maio et al., 1991).

Safety evaluations have been conducted, but limited attention has been paid to the overall system or organization (in the waterway and on the vessel) in which decision-making occurs. Attention usually is directed at subsystems or results; as a result, symptoms of problems are addressed; whether root problems are addressed through corrective measures directed at these symptoms is largely left to chance (Lucas, 1992; Mackenbach, 1992; NRC, 1983). Misdirected emphasis (for example, on symptom-based safety improvement measures) can result in overconfidence in the safety measures and hardware reliability, or in complacency, lack of attention to underlying causes of accidents (Lucas, 1992), and ineffective allocation of resources.

Assessments of risk factors that affect vessel operations (Box 1-5) most often are made informally by mariners while they are navigating or maneuvering their vessels. Risk in ports and port approaches, waterways, and river systems supporting ship navigation varies according to channel and waterway dimensions, configurations, and length; hydrodynamics; commodity types and flows; vessel types, hull forms, sizes, propulsion and steering systems; vessel loading; traffic types, patterns, density, times of movement; tides and river stages; and the presence of port and waterway structures. As all of these factors vary among ports and waterways, so too does the probability that an accident may occur. The interactive effect of these risk factors must be understood and effectively addressed in determining what opportunities exist for improving safety performance. These effects are examined in Chapter 4.

Changes in the Marine Navigation and Piloting System

Over the past several decades, marine transportation has been transformed in form and character. Ships and barges have become bigger and more unwieldy, but improvements in navigation channels to ensure adequate margins of safety for maneuvering lag years behind these changes in vessel design and operating characteristics (NRC, 1985, 1992a). Shiphandling is complicated by modern ship-propulsion systems that sacrifice maneuverability in favor of fuel economy. Yet, some of the latest-generation ships have positioning and control systems that make it possible to navigate more precisely than ever before, given the advanced human skills needed to operate them successfully. The scale of potential harm has also expanded greatly with vessel size. Petroleum, chemical, and liquified gas cargoes are transported in such quantities that a single-ship disaster can have catastrophic consequences for port facilities, population centers, and to local and regional environments. In the busiest ports and waterways, marine traffic has become more dense and diverse. The implications and effects of all these changes are not always readily apparent nor are they well understood from a systems perspective. These changes must be recognized and their effects understood so that enhancements to human systems and advances in technology can be applied effectively to improve navigation safety in a competitive economic environment. However, implementation of improvements is complicated by misconceptions regarding the structure and performance of the marine navigation and piloting system. Further, there is a public perception that preventing tanker accidents is the major marine transportation issue. Although understanding the causes, consequences, and implications of marine accidents that result in major pollution incidents is important, an understanding of the navigation and piloting of all categories of merchant vessels is needed in order to identify and correct systemic problems.

The continuing, polarized debate over pilot roles, performance, and licensure, for example, lacks precision. Although much has been written about pilot

BOX 1-5 RISK FACTORS

- **Physical Factors**
  Waterway geometry and configurations
  Hydraulic and hydrologic conditions
  Hydrography
  Environmental conditions (e.g., weather)
- **Vessel Factors**
  Types
  Sizes
  Propulsion and steering systems
  Hydrodynamics
  Maneuvering behavior
  Vessel status/maintenance condition
- **Economic Factors**
  Ship scheduling
  Cargo transfer operations
- **Transit Considerations**
  Cargoes
  Marine traffic
  Duration of exposure
  Navigational aids and support systems
  Waterways management/traffic systems
  Subsystem support (such as tugboats)
- **Potential Consequences to**
  Vessel
  Human life
  Environment
  Economics
  Property
- **Human Systems**
  Decision-making
  Suitability, qualifications, and proficiency of
  Vessel operators
  Bridge team
  Pilots
  Support system personnel
  Work environment

Sources: Appendix D; Maio et al., 1991; Ramaswamy, 1991; Ramaswamy and Grabowski, 1992; Young, 1993.

age issues, no consensus has developed to guide decision-making relative to the effects of change on the marine navigation and piloting system. Distinctions often are blurred between federally and state-licensed pilots, the various types of pilots (such as coastal, bar, river, and harbor pilots and docking and mooring masters), their roles (advisory or directive), and their legal status (voluntary or compulsory). All these characteristics typically are blended into a confusing pool of subjects and issues that confounds informed assessment. This report presents a comprehensive description of piloting practices (Chapter 2), pilotage administration (Chapter 3), and features of a complete pilotage system (Appendix E) to guide informed decision-making regarding pilotage issues.

The degree to which marine safety may be threatened by changes in the character of marine transportation or current responses to them is a difficult question. There is nevertheless a widespread perception among professional mariners worldwide, national marine safety authorities, and the public that these changes could prove detrimental to safety. Some trends of particular concern are reduced crew sizes, employment of lowest-cost crews, and fatigue and stress caused by economic pressure for rapid port turnaround times (Chadwin and Talley, 1992; Intertanko, 1990; Knudson and Mathiesen, 1987; Motor Ship, 1992a,b; NRC, 1990a; Peters, 1993; Safety at Sea, 1990). There is sufficient reason to closely follow all developments in shipping practices and safety performance. So far, safety data and assessment methodologies have not been adequate for this task. Moreover, mariners, including pilots, are reluctant to be specific about their observations of substandard performance and maintenance, and they are known not to keep extensive or detailed supporting records. The following sections present various perspectives on the changes affecting marine transportation, along with a summary of the debate over pilotage.

Marine Industry Issues

Rapid developments are taking place in technology, competition, and public concern, accompanied by increases in operating costs and, especially for tankers, in the costs of marine accidents. All this is occurring during a period of contraction in the U.S.-flag fleet. These factors limit the ability of domestic operators to respond to change. The costs of accidents, especially those that result in environmental damage, have risen dramatically, and it is not yet clear whether preventive measures will reduce the probability that accidents will occur. Thus, there is a relationship between economic, operational, and environmental risks, and to the degree that human health may be threatened, health risks as well. To the extent that operational risk can be reduced, corresponding reductions in economic, environmental, and health risks will follow. Determining how to reduce operational risk without creating unwarranted economic burdens on operating companies, public resources, or the economy is a substantial challenge.

The most obvious change affecting the marine industry is in the standard of care that must be exercised to safeguard the environment. Great public outrage and calls for corrective and punitive action following several major marine casualties and oil spills during 1989 clearly signaled a dramatic increase in public expectations for marine safety. Legislative and regulatory actions by the states and federal government following these events served to greatly increase the liability of operators of vessels involved in a marine accident.

The Oil Pollution Act of 1990 greatly increased the limits of liability of shipowners for damages resulting from oil spills. It also required that they provide evidence of financial responsibility to ensure the financial resources that would be needed to pay for clean-up. The act also left the states free to pass laws setting even higher liability limits for oil spills in their waters. These developments have heightened safety awareness within the marine industry. They have also increased the incentives for improving navigation and pilotage to reduce the economic risk for oil spills resulting from marine accidents (NRC, 1990a, 1991c; OSIR, 1993e,k).

During this period of change, marine transportation of persistent (heavy) oils has continued at unchanged levels, although there appears to have been a change in which companies are providing the service. The increased financial responsibilities have had a number of effects. A small number of U.S. and foreign operators ceased to use their own vessels to transport persistent oil to U.S. ports (or to ports in a few states, including Maine and Maryland). A few others discontinued or reduced investment in improvements in existing vessels nearing the end of their useful life, because of the phase-out schedule for single-hulled tank vessels imposed by OPA 90. These companies instead may employ vessels owned by others that meet the financial responsibility and other requirements of U.S. law but for which they have a reduced degree of operational control (Lloyd's List, 1990a,b,c; Maritrans, 1989, 1993; OSIR, 1990; Plume, 1991; Trench, 1992). The safety implications of such a shift depend on operating practices (including manning and outfitting) and maintenance of the vessels that are used. Since the enactment of OPA 90, the quality of tankers chartered for service to U.S. ports appears to have improved (Arthur McKenzie, Tanker Advisory Center, personal communication, January 15, 1993). Maintaining this trend is an objective of the act's implementation.

Available data are insufficient to monitor fully the safety performance of not only tankers but also a far greater number of other cargo ships with regard to the existing broad range of marine safety requirements. The potential for involvement of vessels other than tankers in marine accidents, including multiple-vessel accidents involving tank vessels, remains a concern but is difficult to quantify.

Only a small percentage of foreign commerce is shipped on U.S.-flag vessels. The ability to control change through local regulation has been reduced, because declining numbers of vessels and crews are under direct U.S. influence with regard to vessel registry or operator licensure. Unilateral action by the United States to dictate the design of the world's fleets and rules for vessel crewing (at least for operations to and from U.S. ports) is possible, because trade with the United States is essential for many ship operators. However, unilateral action has not in the past been viewed favorably by the international community. However, recent tanker accidents have motivated some European countries to consider unilateral action to protect their waters from oil spills. Although such action is a potentially powerful means to improve safety, it must be implemented very carefully to avoid economic conflict with other countries. Regardless, international shipping companies, if they wish to trade with the United States, must meet international standards enforced by the United States as well as any unilateral standards that are imposed.

Technological development of navigation systems is another area of rapid change. Several new technologies have been developed recently that potentially could be employed to reduce the probability of accidents, and thus to reduce risk. These technological developments, discussed more fully in Chapter 6, can provide dramatic improvements in position fixing, steering, information display, and hazard avoidance. Most will require significant changes to operating practices and operational procedures to realize fully their potential. Retrofitting some existing vessels will be difficult and expensive. There are, nevertheless, incentives for operators to consider using advanced technologies. Beyond risk reduction, some technologies offer improved operational efficiency. Any positive measures that are taken also have potential benefits in the form of public acceptance and goodwill for the industry.

However, powerful impediments complicate the implementation of changes that might improve navigation and piloting. The first barrier is the economic condition of the industry. Because of a worldwide oversupply of most types of vessels, freight rates are low. The shipping industry argues that the capital necessary to improve the fleet is scarce. On the other hand, tanker operators trading with the United States are required by OPA 90 to phase out their existing single-hull ships from this trade by the year 2015. Thus, incentives to replace the world fleet with high-technology ships are countered by economic forces (Peters, 1993).

Retrofitting new technology might be attractive for many operators if they could derive operational efficiencies. Current U.S. laws and regulations—many of which were enacted before the new technologies emerged—make it difficult to alter crew manning and operating practices as needed to achieve these efficiencies. Past labor agreements have had similar effect, although there is strong movement in U.S. shipping towards permanent assignment of masters, mates, and licensed engineers. In some cases, these same laws and regulations could even impede the changes in operations that could reduce risk (see related discussion in Chapter 6).

Liability considerations also inhibit adoption of new technologies and practices. Centuries of court decisions with respect to prudent seamanship could not take into account these new technologies and practices. Operators that adopt high-technology navigation systems risk running afoul of legal requirements and precedents that institutionalize practices and procedures based on the use of traditional navigation equipment (now including radar and very high frequency [VHF] radio). As an example, some operators have been reluctant to install electronic charting systems until the legal equivalence of electronic charts to paper charts has been firmly established. Other operators have made these installations, and their bridge personnel are using electronic charting systems for navigation, while retaining older equipment and paper charts to satisfy legal requirements.

What many shipowners perceive to be a lack of coherent national maritime policy seems to be at the root of most of the uncertainty among operators as to the direction that they should take in addressing the new, higher levels of risk. They see little encouragement from the federal government for expanding or even maintaining the U.S.-flag fleet. Shipping laws and regulations are not seen as supporting the changes that shipowners believe are needed (Phillips and Weintraub, 1993). Seeing no effective central management of maritime affairs, operators are concerned that independent action by U.S. coastal states will complicate or adversely affect the U.S. position in international marine safety policy setting.

Change is needed to meet the new challenges of public expectations and increased risk. But changes in operating practices and adoption of high-technology navigation systems are unlikely to be timely or fully effective without a substantial reduction in the uncertainty facing the maritime industry and without the removal of impediments that constrain their implementation and use.

Public Safety Issues

Modern operating and manning practices have increased performance demands on shipboard personnel in pilotage waters—usually the most difficult and demanding portion of modern voyages (see Chapter 4). Adding to this load are the difficulties associated with substandard ships and crews, identified by anecdotal reports (Armstrong, 1980; Cahill, 1983, 1985; Fairplay, 1992a). Substandard performance is alleged for ships of a dozen nations (OSIR, 1993d; Peters, 1993; Salvarani, 1992). Substantial material deficiencies have been detected by Coast Guard inspections of some foreign-flag merchant ships of all types and by pre-charter inspections. Both the Coast Guard and the IMO have alleged substandard oversight by some classification societies that inspect and certify vessel seaworthiness (Bangsberg, 1992; Fairplay, 1992a; Irvine, 1993; Kime, 1992; OSIR, 1993d; Porter, 1994). For example, according to pre-charter inspections by one oil company, up to 20 percent of tankers in 1992 that it considered chartering did not fully meet international and applicable company chartering standards (Irvine, 1993). Further, a very large number of vessel owners or investors own only one or two ships. There are about 3,250 oceangoing tankers, but the average tanker fleet consists of only about 1.7 ships (Irvine, 1993). The general manning practice of single-ship owners and management companies is to obtain crews as needed on the world maritime labor market; competitive factors are such that there is little incentive for owners or management companies operating in this fashion or charterers to invest in professional development programs (Peters, 1993). Such practices are not only a concern to marine safety authorities, but also to the operators of larger tanker fleets (Intertanko, 1990).

Over the past several decades, the operational safety of ships, measured in terms of marine casualties, has improved overall (Knudsen and Mathiesen, 1987; Marine Log, 1993; NRC, 1990a, 1991c; USCG, 1987). Since 1989, the number of ship losses, ship losses in tonnage, volume of oil spilled by vessels in U.S. waters, and number of vessel spills in U.S. waters and worldwide have decreased steadily (Marine Log, 1993; OSIR, 1991, 1992, 1993i). Yet a number of factors, including the increasing age of commercial fleets and an associated increase in maintenance problems, suggest that this trend may have reached a limit and could be reversing.

After steady reductions in the numbers of ships lost over a 10-year period, total losses jumped sharply by 27 percent in 1991. Losses of life and gross tonnage surged as well. In 1992, two large oil spills from tankers accounted for nearly 27 percent of the total number of gallons spilled worldwide, an increase in volume spilled over the two preceding years (OSIR, 1992, 1993i; Porter, 1992b). This was followed in early 1993 by several major oil spills involving tanker accidents off the coasts of Europe and Southeast Asia (OSIR, 1993e,f,g,i,j; Welch, 1994). Possible explanations for the observed increases include aging of the world's merchant fleets and alleged deterioration in the quality of ships' crews (Bangsberg, 1992; Peters, 1993; Porter, 1992a; Tecnitas, 1992). Comprehensive data to support these hypotheses were not available; previous National Research Council studies have identified gaps in marine safety data and called for research to fill them (NRC, 1990a, 1991a). However, the Coast Guard reports that too many deficiencies are being detected in foreign-flag tankers through its boarding program and that "alarming discrepancies" are being found with regard to the International Safety of Life at Sea (SOLAS) convention and U.S. regulations (Kime, 1992).

The Marine Accident Record

In general, the marine accident record indicates that the marine navigation and piloting system is a safe system. Apparent reasons for this performance level include:

- the slow speed at which most action occurs, usually—but not always—providing time for human operators to recognize and recover from mistakes;
- an operating environment that usually does not lead immediately to catastrophic results such as total loss of a vessel; the more extreme consequences

often occur well after the initial event, especially in unprotected waters, as the vessel is exposed to various environmental conditions (Cahill, 1983, 1985; NTSB, 1990);

- the nautical rules of the road, which if used correctly provide adequate procedures for preventing collisions in interactions between two vessels (Cahill, 1983; NTSB, 1972, 1981, 1984, 1988a, 1991a); and
- the conscientious performance of operating personnel, even when mistakes are made (Paramore et al., 1979; Reason, 1992).

Particular credit is due the independent marine pilots who play a distinct role in providing expert navigation and piloting services for vessel masters and bridge teams unfamiliar with local ports (Armstrong, 1980; MacElrevey, 1988; Nautical Institute, 1991a; Plummer, 1966; Ramaswamy and Grabowski, 1992; Reid, 1986).

Yet, despite the considerable care and sound judgment exercised by the many reputable mariners and operating companies, a substantial number of marine accidents occur nationwide. Most are neither newsworthy nor catastrophic. But a select few have been sufficient to erode public confidence in the safety performance of the industry at large and in navigation and piloting practices. The grounding of the *Exxon Valdez* in Prince William Sound, Alaska, with a major spillage of crude oil (Alaska Oil Spill Commission, 1990; Davidson, 1990; NTSB, 1990), was followed within a year and a half by other major tank vessel accidents in or near U.S. coastal waters (NTSB, 1991a,b; OSIR 1989a,b,c; USCG, 1990a). Problems with navigation and shiphandling in these and other marine casualties were identified as key causal factors. It is intriguing that most marine accidents involving commercial vessels also involved seasoned rather than inexperienced personnel, pointing to the importance of continuing professional development and evaluation. Many accidents also occurred during moderate or better weather (AWO, 1992b; Cahill, 1983, 1985; NTSB, 1980, 1988a, 1989a, 1990, 1991a; Paramore et al., 1979; TBS, 1985).

In the public debate leading to passage of OPA 90, questions were raised about the professional qualifications of merchant mariners and marine pilots, the programs that lead to their qualification, and professional oversight and discipline. These concerns have not abated. Concerns have been expressed by many interested parties including Congress, the National Transportation Safety Board (NTSB, 1989a,b, 1990, 1991a,c), state legislatures and regulatory agencies (Journal of Commerce, 1992b; OSPR, 1993, 1994; Wastler, 1993b), federal regulatory agencies (USCG, 1989), and the public (Abrams, 1992a,b; Crowley, 1991; Davidson, 1990; Journal of Commerce, 1992a; Nalder, 1989a,b; Seattle Times Company, 1989). The qualifications and performance of pilots, and the benefits of federal versus state pilotage systems, are highly controversial, polarized, politicized, and intensely debated issues.

THE PILOTAGE CONTROVERSY

Examinations of pilotage by the marine industry, government authorities, and the public have focused on three basic issues: safety (including environmental safety), administration, and economics. Safety issues are sometimes intermingled with and overshadowed by underlying economic interests. The merits of the federal and state systems of pilotage have been debated for more than a century. The modern debate is often characterized by an incomplete understanding or representation of piloting practices and professional development and assertions about safety performance and data based on specific points of view.

Recent examinations of pilotage have targeted pilot safety performance in specific accidents. Disciplinary processes following marine accidents also have been emphasized. Some interested parties and observers advocate making the federal pilot license superior to state licenses to improve this form of discipline (Ashe, 1984: NTSB, 1988a). Others endorse the state pilot system as superior in effectiveness and discipline (Crowley, 1991; Leis, 1989, 1992). At the same time, many mariners express concern about the expertise available in the Coast Guard for the establishment of pilotage qualification requirements. Some express a belief that Coast Guard personnel have limited piloting expertise or that their expertise is not comparable to that required to pilot commercial vessels. On the other hand, the Coast Guard considers that the credentials of personnel assigned to pilotage administration are generally adequate to the task (see Chapter 3).

No acceptable performance measure has been developed for gathering and normalizing safety data to allow comparative assessment of pilot performance in different ports or for different categories of vessels (even those operating in the same locale). Operating risks vary greatly by service area, as do piloting tasks, for example, crossing the bar versus docking a ship in a confined waterway (Booz, Allen and Hamilton, 1991). The available data provide only a limited sense of the causal relationship of pilotage to marine casualties; moreover, the data typically focus on individual vessels rather than on ship, shore-based, or human systems. The Coast Guard is developing a prototype exposure database for multidimensional risk analysis of causal relationships in marine accidents (Abkowitz et al., 1985; Hantzes and Ponce, 1991; USCG, 1993c). In-depth marine accident investigations conducted by the NTSB and the Coast Guard provide useful insight on specific events but are less helpful in expanding understanding of individual pilot performance or in explaining how this knowledge might relate to decision-making, pilot professional development, the use of navigation technology, or a system-wide perspective on safety.

Differences in pilot training and licensing standards and oversight also have been cause for considerable controversy. Pilots appear to be held to more rigorous standards in some jurisdictions than in others. Moreover, some mariners who provide pilot, docking, or mooring services to U.S.-flag and foreign-flag ships in foreign trade are not presently required to be licensed. In some cases, as in Kill Van Kull and Newark Bay in the Port of New York and New Jersey, docking masters possessing but not serving under the terms of a Federal First Class Pilot's License or endorsement direct and control vessel maneuvering during transits of up to 19 miles, although shorter distances are more common (Booz, Allen and Hamilton, 1991; Cahill, 1985).[5] Some marine transportation companies contend that the extensive experience of the docking masters and vessel operator concerns about operational safety and costs of marine accidents work to provide comparable levels of safety performance even where official governance does not fully cover licensure. Whether or to what degree this is correct is an issue.

Debate continues over whether and to what extent state pilots are subject to more rigorous training and evaluation than are federally-licensed pilots and whether discipline is applied more consistently nationwide by the Coast Guard than by state governing authorities (Ashe, 1984; Booz, Allen and Hamilton, 1991; Cantwell, 1992; Crowley, 1991; Deane and Peterson, 1992; Journal of Commerce, 1989, 1992a; Leis, 1989, 1992; Mongelluzzo, 1994; Nadeau, 1992; Neely, 1992; Ramaswamy and Grabowski, 1992; Sankovitch, 1993). Whether the differences between federal and state pilotage have translated into unequal safety records also is debated; study results are mixed and are open to question because of the lack of standard methodologies for gathering and assessing safety data. Two analyses of the Coast Guard's casualty data indicate that safety levels of federal pilots are equal to or better than those of various state groups (Booz, Allen and Hamilton, 1991; USCG, 1993c). But other examinations claim much higher losses for federal pilots when they are performing the same tasks as state-licensed pilots (Leis, 1989, 1992). The differences in results are related to study methodologies and the safety data chosen for analysis (see Appendix D).

Some comparisons between the federal and state pilotage systems are inevitable, because federal pilot licenses are required or used in various ways within each state system. However, comparisons of safety performance are not meaningful without a standard or benchmark. Instead of directly comparing the federal and state pilotage systems in its analysis, this report compares each form of pilotage regulation with the features that the committee considers central to a complete pilotage system (Appendix E). In the absence of definitive safety data, comparisons of each form of pilotage oversight to the central features of a complete pilotage system can serve as the basis for informed decision-making as to how marine pilotage might be improved to assist in reducing operational risk.

[5] The Coast Guard-issued a notice of proposed rule making in July 1993 that would fill some existing gaps in state pilotage coverage by requiring a federally-licensed pilot to direct and control the navigation vessels in foreign trade that operate in certain designated waters of California, Hawaii, Massachusetts, New York, and New Jersey (FR 58[130]:36914-36918).

2

Piloting Practices

SUMMARY

Piloting, as commonly understood, is a straightforward matter; a qualified local expert boards a ship at sea and brings it safely into its anchorage or berth. Actual piloting practices are far more complicated than this, and are poorly understood, even within the marine community. By international tradition, a marine pilot is a master mariner who, not being a member of a vessel's crew, provides expert local knowledge required to bring the vessel safely into port. The term "pilot" sometimes is used to refer to a vessel's officer who is controlling its maneuvers. Pilots and piloting in the United States vary according to areas served, the functions performed, and differing requirements for local knowledge and specific shiphandling skills. Pilots may or may not be members of a vessel's crew depending on governance and, in the case of domestic shipping and the towing industry, depending on company operating policies as well. The term marine pilot is used in this report to mean a locally based master mariner who is independent of the vessel (that is, not a ship's officer or other member of the crew). Virtually all marine pilots in the United States hold a license issued by a recognized federal or state-level pilotage authority. Individuals that specialize in docking and mooring may or may not be marine pilots in the strictest sense, depending on their professional affiliation and the range of services provided.

Professional development and licensing requirements vary by governing authority, but individual preparations to meet these requirements remain a personal responsibility regardless of licensure. Some shipping and towing companies encourage or assist their masters and mates in obtaining federal pilotage credentials, primarily to improve operational safety aboard their vessels and to reduce

risk. Organized federal and state marine pilot associations and some docking master associations have organized professional development programs, or they otherwise assist their pilot candidates in obtaining service or other prerequisites for pilot's licenses or endorsements from federal or state-level governing authorities, or in some cases, both. Although qualifications for pilots still emphasize the use of expert local knowledge and visual cues, pilots make extensive use of navigation technology. Gyrocompasses, voice radio, rudder angle indicators, and basic radar have become standard equipment that is integral to piloting. Electronic charts with a highly accurate real-time positioning capability, once proven reliable, likely will become assimilated into standard operating practice as well.

Most pilotage systems have common elements that are universally considered essential for developing and maintaining pilot expertise and system performance. Principal features include measures for professional development, accountability, standards, and organization. Three basic pilotage models—public, corporate, and independent—are in use. None stands out as most effective or efficient; highly professional pilot services are being provided in each form. Changes from one form to another usually are related to economic factors rather than to actual piloting practices and safety performance. Pilot response to the expectations of their profession seems to be the dominant factor in the effectiveness of pilotage, regardless of the pilotage model used.

INTRODUCTION

This chapter describes piloting practices in the United States, the context for the analysis in the chapters that follow. The controversial issue of professional regulation of pilots is introduced; a detailed examination is presented in Chapter 3. Beginning in this chapter and continuing in the next, comparisons are made and lessons drawn from pilotage systems on the Great Lakes, in British Columbia, in European countries, and for the Panama Canal. Finally, the central features of a complete system of pilotage, as envisioned by the committee, are presented. These elements are drawn from discussions and correspondence with pilots in the United States, Europe, Canada, and the Panama Canal, and from published accounts, and they provide a baseline to which existing pilotage systems can be compared. Several foreign pilot systems are described in Chapter 3 and Appendix F. The piloting operating environment, still another complicating factor in pilotage and the use of navigation technology, is developed in Chapter 4.

PILOTAGE OVERVIEW

The common perception of a pilot is of an individual who boards a ship from a pilot boat at sea to bring it safely into port. While there are many pilots that fit this image, pilotage is far more complicated. Even within the marine community, the levels of functional and administrative complexity are not well understood. This section introduces and describes types and locations of pilots, governance, master–pilot relationships, pilot responsibilities, compensation, professional development, and relationships to modern technology.

Bar pilot stepping from a pilot boat to a pilot ladder while boarding a ship off San Francisco in good weather. (Joseph A. Zygaj, *San Francisco Bar Pilots*)

Pilots

A pilot is traditionally a mariner with expert knowledge of local waters and special shiphandling skills. The pilot directs and controls the movement of a vessel through near-shore and inshore waters (referred to as pilotage waters or pilot grounds) unfamiliar to the master or provides navigation advice to or through the master for this purpose. The pilot is expected to integrate local knowledge with operational information to effect a safe passage. However, by tradition, admiralty law, and legal precedent, the master always remains in command and is ultimately responsible for the safe navigation of the vessel, including the actions of the pilot (except that in the Panama Canal, the Panama Canal Company accepts a higher degree of responsibility and liability in exchange for a higher level of control over each vessel [MacElrevey, 1988; Parks, 1982]). Thus, in pilotage waters, the responsibility for piloting typically is shared (Crenshaw, 1975; MacElrevey, 1988; Meurn, 1990; see Parks, 1982, 1988, for legal definitions and case law).

The pilot may be an independent professional expert whose services are hired by a vessel. Or, a pilot may be a member of a vessel's crew with expert local knowledge of the pilotage route. While describing a crewmember as a pilot is not common practice internationally, this attribution is well established in the U.S. coastwise trade and the inland towing industry. This report distinguishes "marine pilots" as locally based master mariners who provide pilotage service. Marine pilots are characterized as

- holding a pilot's license issued by a recognized pilotage governance authority;
- members of a pilots' association (or a company or governmental entity that solely provides pilotage services);
- independent contractors (except in three cases where they are company or municipal employees);
- not members of a vessel's crew (and thus independent of the crew and the vessel); and
- not otherwise affiliated with or employed by a shipping or towing company.

Thus, where a master or mate is qualified and serving as a vessel's pilot, the individual would not be considered a marine pilot as the term is used in this report.

Types of Pilots

Five trade designations are used in this report for types of pilots according to areas served, functions performed, and requirements for local knowledge and specific shiphandling skills.

1. A *coastwise pilot* guides domestic vessels into and out of domestic ports, and between ports when transits are made through inland waters, such as Boston to New York. A coastwise pilot typically stays aboard for the duration of the voyage whether the vessel is operating along inland passages or coastwise, although in some cases port-specific pilotage services are provided.
2. A *bar pilot* (sometimes referred to as a "sea pilot") directs the movement of the vessel across the "bar," to and from the pilot boarding area (the pilot grounds) and the inner harbor or river.
3. A *river pilot* directs the movement of vessels in river systems.
4. A *harbor pilot* directs the movements of (transports) a vessel in harbors, including shifts to and from anchorages and berths. The term "Navy pilot" refers to an individual employed by or a member of the U.S. Navy who provides harbor pilot services for Navy ships.
5. A *docking master* (sometimes referred to as a docking pilot) docks/undocks vessels at a berth or mooring, usually with the assistance of tugboats (mooring masters perform similar duties for offshore mooring buoys, usually without assist tugs).[1]

[1] There is considerable debate as to whether a docking master is a pilot in the strictest sense. Technical aspects of the debate are based on the functions performed. However, the principal issue is that official acknowledgment of docking masters as "pilots" would strengthen the case for issuance of state or federal licenses specific to the services they provide (see Chapter 3).

Traditionally, a "dockmaster" was an assistant to a harbormaster, who supervised passage of a vessel through a locking system or into a berthing, either from a position ashore or from the vessel. "Dockmaster" also was used to refer to the individual responsible for dry-docking a vessel (Geen and Douglas, 1983; McEwen and Lewis, 1953). Today, docking and undocking services, usually with tugboat assistance, are typically provided by pilots except in most East Coast ports. In these and some foreign ports, docking masters who specialize in docking and undocking vessels are available. These individuals are not necessarily marine pilots unless affiliated only with an independent pilot association. Some docking masters, notably in the Port of New York and New Jersey, conduct the majority of intraport ship movements (vessel transport) as well (see Chapter 3). When transporting a vessel (up to 19 miles on one route), a docking master is, in effect, performing harbor pilot duties.

When providing service to a U.S.-flag ship in domestic trade, docking masters do so under licensing requirements for federal pilotage. When providing service to a vessel in foreign trade, docking masters are not at present covered by state-level licensing requirements. The Coast Guard proposed rules in July 1993 that would require federal pilotage for foreign trade vessels making intraport transits in certain designated waters in New York and New Jersey, transiting designated waters in Massachusetts, and navigating at certain offshore marine oil terminals in California and Hawaii (FR 58 [130]:36914-36918). The principal issues are whether an individual is qualified to direct and control the movement of a vessel and whether pilotage requirements adequately ensure the quality of professional service that is provided. These issues are central to pilotage performance and administration throughout the marine navigation and piloting system.

The term "branch pilot" is also a common piloting term. It is derived from a certificate of competency formerly issued to a pilot by the Trinity House in England. The certificate authorized the individual to pilot ships on certain specified waters. A full branch pilot is an individual without limiting restrictions on the certificate of competency (McEwen and Lewis, 1953). This traditional terminology frequently is incorporated into the titles and licenses of marine pilots issued under the authority of coastal states.

BOX 2-1 A BRIEF LEGAL HISTORY OF PILOTAGE

Much of the history of pilotage regulation in the United States has been framed by rivalry between federal and state jurisdictions. The Constitution grants to the Congress authority to regulate all pilotage but leaves the states free to regulate any pilotage matters not covered by federal law. From the first Congress in 1789 until the mid-1800s, Congress did not use its authority, and the states regulated all pilotage, as they had done since colonial times. In the mid-1800s, after the introduction of steam vessels, the Congress began to play a role in pilotage regulation, requiring federal pilots on coastwise seagoing steam vessels in domestic trade. This legislation effectively limited state authority to pilotage not covered by federal law, that is, to ships engaged in foreign trade, both foreign-flag and U.S.-flag vessels sailing "on registry." This division of jurisdiction between the federal government (acting through a federal agency, now the Coast Guard) and the states has continued ever since. The Tank Vessel Act of 1936, as later interpreted by the courts, extended federal pilotage requirements to seagoing tank vessels carrying flammable, explosive, or dangerous cargoes in coastwise domestic trade. Sources: Ashe, 1984; AWO, 1992b; Crowley, 1991; Parks, 1982, 1988.

As used in this report, the terms "federal pilot" or "federally-licensed pilot" refer to mariners, including masters and mates, holding either a Federal First Class Pilot's License or Federal First Class Pilot's endorsement on their Coast Guard-issued marine license. The phrase "independent federal pilot," as used in this report, refers to independent marine pilots holding only a Federal First Class Pilot's License or endorsement and who routinely serve under the terms of that license. Although virtually all marine pilots in the United States (including state-licensed pilots) hold a Federal First Class Pilot's License (or Federal First Class Pilot's endorsement permitting them to serve as pilot), some do not provide service under the authority of these licenses and are thus not officially accountable, as described in this chapter.

Numbers of Pilots

About 4,500 individuals hold Federal First Class Pilot's Licenses or endorsements. Of these, about 1,000 are independent marine pilots who hold pilot licenses issued by coastal states or local boards or commissions under enabling state authorities. Of the total number, about 100 are marine pilots holding only a federal pilot's license or pilot's endorsement on their deck officer's license as master or mate, fewer than 100 are docking masters or mooring masters, and about 40 are registered (Great Lakes) pilots. The remainder are individuals holding federal pilot endorsements on their U.S. Coast Guard-issued licenses as masters or mates.

Ninety-three active pilot and docking master organizations were identified in the United States, as follows:

- 62 state pilot organizations, the operations are regulated by board or commissions (includes 1 group of state-licensed pilots who are port authority employees [Mobile, Alabama], 1 pilot association with a commission to provide pilot services but whose members only hold federal licenses [San Diego]);
- 11 organizations consisting solely of marine pilots holding only a federal pilot's license or endorsement (including 3 federal pilot associations in the Mid-Atlantic states and Louisiana; 3 registered pilot pools on the Great Lakes; 1 independent pilot group in Alaska (Kuskokwim Bay and River); and in California, 1 employee-owned pilot corporation under contract to a harbor commission (Long Beach), 1 group consisting of port-district civil service employees Angeles), and 2 self-governing pilot associations (Port Hueneme–Oxnard and Humboldt Bay–Eureka));

(Los

BOX 2-2 SOLICITED EXPERT ACCOUNT: PILOT ROUTESPORT OF BALTIMORE AND UPPER CHESAPEAKE BAY RICHARD W. OWEN, *ASSOCIATION OF MARYLAND PILOTS*, AUGUST 1991

The route from Cape Henry, Virginia, to Baltimore is 150 miles in length and comprises 60 miles of dredged navigational channels and 90 miles of more open waters characterized by a variety of natural deep-water sections bounded by hazardous shoals. This route has a controlling depth of 50 feet, recently increased from 42 feet by an extensive dredging project at a cost of about $200 million. The second major route serving the port is the northern approach via the Delaware Bay and River through the Chesapeake and Delaware Canal and the northern Chesapeake Bay approach channels to Baltimore. The distance from sea to Baltimore via this route is 115 miles, the first 65 miles of which fall under the jurisdiction of the Delaware River pilots. The Maryland pilots customarily relieve the Delaware River pilot at Chesapeake City, Maryland, for the remaining 50-mile transit to the port. The controlling channel depth in this northern approach is 35 feet. The Association of Maryland Pilots services over 200 miles of waterways in the largest estuary of its kind in the nation. Of those 200 miles, over 100 miles are dredged navigation channels ranging in width from the narrow 450 feet found in the fully restricted (i.e., canal with walls) Chesapeake and Delaware Canal and in the northern approach channels through a variety of intermediate widths to the 1,000-foot-wide entrance channel at the mouth of the bay.

BOX 2-3 SOLICITED EXPERT ACCOUNT: PILOT ROUTE PORT OF CHARLESTON, SOUTH CAROLINA WHITEMARSH S. SMITH, III, *CHARLESTON BRANCH PILOT'S ASSOCIATION*, JULY 1991

Our pilot routes encompass the Charleston Bar and Harbor. The "bar" is that area offshore of the port where the depths of water are such that deeply laden vessels could not safety call for risk of going aground were it not for a channel through and over that bar. Thus, the bar for the Port of Charleston begins on the continental shelf, at a natural depth of 42 feet mean low water, some 12 nautical miles seaward of the headlands, and about 10 nautical miles seaward of the jetty entrance. The pilot station is in the vicinity of sea buoy "C," now located immediately offshore of the bar on the centerline of the Fort Sumter range. This entrance channel is a U.S. Army Corps of Engineers-maintained channel with a project depth of 42 feet mean low water and a width of 1,000 feet. The harbor of Charleston is the estuary inshore of the jetty entrance. It embraces the Corps of Engineers and privately maintained waterways and channels of the Cooper, Ashley, and Wando Rivers. The Cooper River is navigable upstream to oceangoing shipping some thirty-plus miles from sea buoy "C." The Wando River is navigable to oceangoing shipping for about 25 miles from sea buoy "C." The Ashley River is navigable to oceangoing shipping for only several miles upstream of its confluence with the Cooper River because of several factors including depths of water, bridge clearances, and bridge alignments. All three rivers merge inshore of the jetties. The confluence of the Ashley and Cooper occurs about two miles inshore of the headlands, creating a large inner body of water that has permitted the establishment of several anchorages. The Wando merges with the Cooper about three miles upstream of the Ashley-Cooper confluence. Pilot routes at Charleston seaward of this confluence are imbedded in channels cut into the harbor bottom and surrounded by open water. Seaward of the jetties, 10 miles of the pilot route is on the Atlantic Ocean. Upstream of the confluence of the Ashley and Cooper, the pilot route is marked by turns and bends that follow both man-made and natural channels. The tidal current does not parallel the channels at most locations, inshore or offshore.

- 1 pilot corporation, consisting of pilots holding state and federal licenses, that provides service to Navy ships (in New York Harbor); and
- 19 docking master associations (on the East Coast).

An undetermined number of individuals "act as pilots" on towing industry vessels under 10,000 gross tons as provided for by federal law. The distribution of pilot organizations providing services to commercial shipping is shown in Figures 2-1 through 2-4.

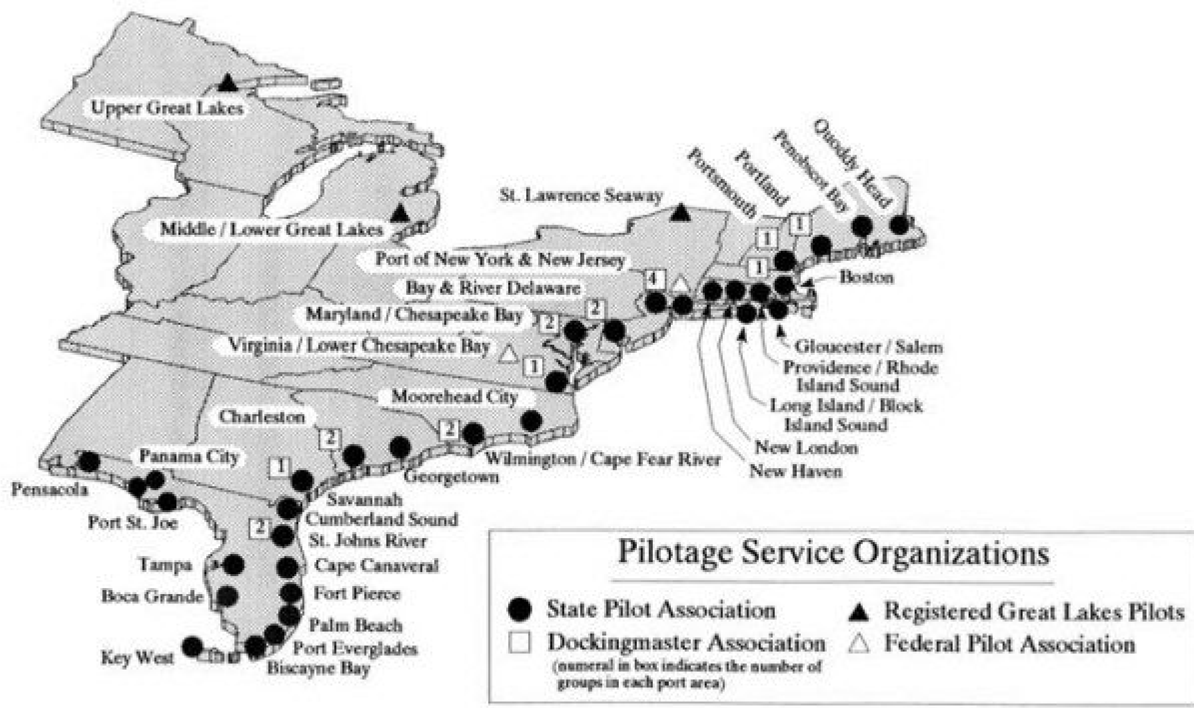


FIGURE 2-1 Location of East Coast and Florida pilot and docking master associations.

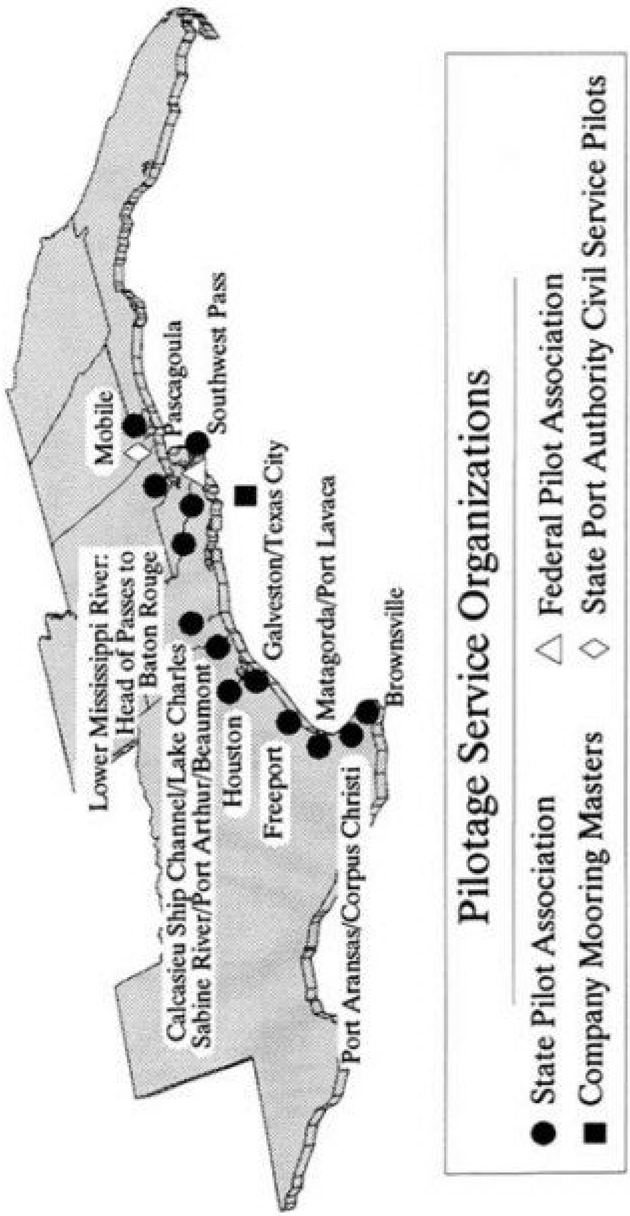


FIGURE 2-2 Location of Gulf Coast pilot associations and mooring masters.

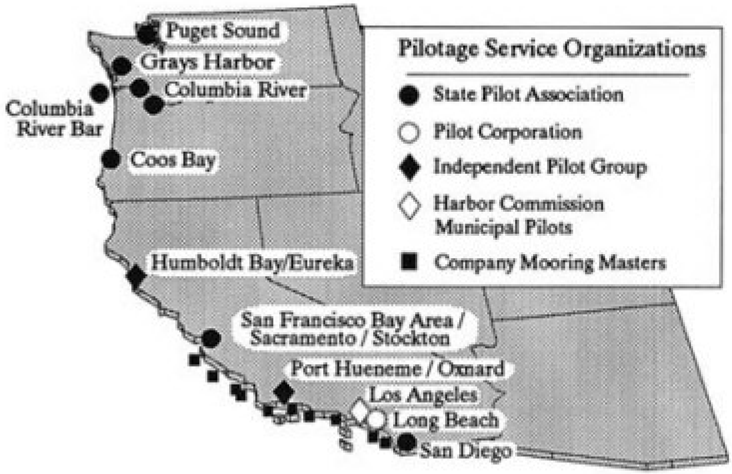


FIGURE 2-3 Location of West Coast associations and mooring masters.

FIGURE 2-4 Location of pilot associations and mooring masters in Alaska and Hawaii.

Pilot Services

Pilotage on the East Coast generally evolved from the U.K. Trinity House guild–system tradition (which was only recently restructured) (Herberger et al., 1991; Appendix F). Pilotage in other U.S. ports evolved as a response to market needs, but it generally follows the association concept in organization. Regardless of the organizational structure used, safe navigation in pilotage waters depends upon the skill and judgment of the pilot. The pilot works under varying traffic and environmental conditions. Unless a ship's officer, the pilot works on many different types of vessels with varying equipment, maneuvering behaviors, and levels of crew performance. The pilot also must be able to work with the expanding range of navigation technologies and configurations. Pilots perform navigation and piloting functions, and for the vessels served by pilots, may coordinate vessel movements to some extent. The pilot determines when and where

BOX 2-4 SOLICITED EXPERT ACCOUNT: PILOT RESPONSIBILITIES LOU BETTINELLI, INTERPRET *PILOTS AGENCY,* MAY 1991

In order to fulfill his responsibility to the captain, it is essential that the pilot establish a comprehensive master–pilot relationship. The captain has intimate knowledge of his ship's handling characteristics, with any idiosyncrasies that may exist. The pilot has specific local knowledge of the port, including weather, tide and current conditions, and the other hazards of the route, and he has extensive shiphandling experience, in a more generic sense. Maximum safety is assured when the pilot and master work together, sharing their separate and distinct areas of expertise in pursuit of a common goal, the safe passage of the vessel. In this pursuit, the pilot must take care to ensure that he is provided with as much information as the captain can give about the handling characteristics of the vessel, as well as the condition of all the equipment that impacts on safe navigation. In return, the pilot must provide the captain with all pertinent information concerning the hazards of the route and the anticipated course of travel.

The interaction between the pilot and shipboard personnel also extends to the rest of the bridge team. It is essential that the pilot recognize his own limitations and acknowledge the need for input from the ship's bridge team. The pilot must know what information is important to the safe navigation of the vessel, and he must know how to get it. A good example of this is the use of collision avoidance systems. The pilot must be familiar with the use of these systems; however, his familiarity must be with the general capabilities of these systems and how these capabilities enhance the safety of piloting. The shipboard personnel must be familiar with the operation of the specific system installed on their vessel. The pilot must have the ability and knowledge to interact with the ship's personnel in order to take advantage of their knowledge of the ship's navigation systems.

to maneuver the vessel and coordinates queuing and horizontal separation with other traffic.

During a vessel's transit of pilotage waters, a single pilot may provide all services, from crossing the bar through anchoring or docking evolutions, or up to several marine pilots and a docking master may be used. For example, pilotage in most East Coast ports usually is handled first by a bar pilot and then a docking master. On the West Coast, in all Gulf Coast ports (except Mobile, Alabama, where some intraport moves and docking evolutions are conducted by state-licensed pilots who are port authority employees), and in several East Coast ports, a single pilot handles all piloting and docking tasks. For long routes, such as an uninterrupted ship transit up the lower Mississippi River from Southwest Pass to Baton Rouge, up to three marine pilots (one bar and two river pilots, more in unusual circumstances) may be used, depending on vessel destination, transit speed, and river conditions.

Pilot Grounds

The location of the pilot boarding area for port entry is based on operational needs. In some localities there is more than one boarding area. This results when the nature or length of the pilot route necessitates the use of more than one pilot because there is an operational need for pilots to specialize on certain route segments or because of the duration of a normal transit. The offshore boarding area is located seaward of the bar or entrance channel at a sufficient distance to provide an adequate margin of navigation safety for inbound and outbound vessels.

The pilot boarding area may be inside or outside of the United States' three nautical mile territorial sea, which is the limit of coastal state and federal jurisdiction for pilotage. The extension of the nation's international boundary to 12 nautical miles was not applied to all federal or state marine statutes, including pilotage (USCG, 1989). Pilot services are voluntary outside of three nautical miles, but the pilot normally provides all normal pilotage services during the full passage even if a vessel was boarded farther offshore. In some cases, pilot services are not provided to the seaward extension of the three nautical mile territorial sea because of the absence of operational needs for the pilot to board that far offshore.

Governance

Both state and federal governments have important roles in pilotage jurisdiction and administration. Although the Constitution grants to the Congress authority to pass laws regulating virtually all pilotage, the Congress has exercised this power only to a limited extent, leaving the states free to act in matters not covered by federal law. Thus, for more than a century, the Congress has assigned to federal agencies (now the Coast Guard) exclusive authority to regulate pilotage of seagoing coastwise vessels in domestic trade, and since 1960 vessels navigating on the Great Lakes, leaving to the seaboard states the regulation of pilotage of vessels in foreign trade. A vessel in coastwise trade therefore must employ a pilot holding a Coast Guard-issued federal pilot's license of endorsement. A vessel in foreign trade, navigating the same waters, must engage a pilot licensed under the laws of the state with jurisdiction over those waters. Because a U.S.-flag vessel may engage in both foreign and coastwise trade, the same vessel with the same crew carrying identical cargoes may be subject to state pilotage on one voyage and federal pilotage on the next one. The two sets of pilotage laws and regulations are significantly different in many respects, as discussed in Chapter 3. A consequence is that the formal requirements governing qualifications to pilot certain U.S.-flag vessels can vary substantially without regard to whether task performance has changed. Detailed assessments of Great Lakes pilotage are available elsewhere (DOT, 1988, 1990); examination beyond developing points of comparison is outside the scope of this report.

Pilot boarding area just seaward of Los Angeles Harbor. The pilot boat is shifting the marine pilot from the outbound U.S.-flag container ship to an inbound foreign-flag container ship. The assist tugs are shifting from the outbound to the inbound ship to await the pilot's instructions once the pilot has boarded from the pilot boat.(William A. Creelwman)

Master-Pilot Relationships

The U.S. Supreme Court has described a pilot as the "temporary master" (master pro hoc) (*Coolly v. Board of Wardens for the Port of Philadelphia, 23 How. [U.S.] 2890*) in regard to navigation, in charge of "the whole conduct of the navigation of the ship" (*Rally v. Troop, 157 U.S. 386*; Parks, 1982). Federal law requires that a coastwise vessel in pilotage waters be under the "direction and control" of a federally-licensed pilot at all times when it is underway in U.S. navigable waters (a vessel is "underway" all times except when it is anchored, moored to the dock, or aground [46 U.S.C. 8502]). Under the federal system, a coastwise vessel may be piloted by its master or mate if the officer has a pilotage endorsement on the individual's officer's license. The federal system is thus very different from pilotage in its more traditional sense as used internationally, in that it primarily sanctions pilotage by a ship's officer rather than by an independent local pilot.

Pilotage under state systems is performed by independent professional pilots, the more common international approach to pilotage. The extent of the pilot's responsibility for navigation of vessels in foreign trade and the pilot's relationship to the master are not always defined by state law, but the pilot generally has primary responsibility for navigating the ship to its destination. Unlike federal pilotage statutes, state pilot laws (except in some West Coast jurisdictions) do not make compulsory pilotage for docking, undocking, mooring, or anchoring maneuvers, although a state pilot might be required to be aboard and available on the vessel's bridge during these maneuvers. Traditionally, the master has been considered most qualified to perform docking evolutions because of familiarity with the ship, although modern operational practices have reduced such familiarity (see Chapters 1, 3, and 7). State-licensed pilots contend that establishing compulsory pilotage for docking would interfere with the master's legal right to conduct docking maneuvers or to designate whomever the master considers most qualified under prevailing conditions (usually the pilot). In both state and federal systems, whenever the pilot is required to be in charge of a vessel's navigation, the pilot's direction and control is subject only to the preemptive command responsibility of the vessel's captain (MacElrevey, 1988; Parks, 1982).

Under the laws of some states, the pilot is said to be the "servant" of the shipowner. Although these laws appear to be intended to relate primarily to the owner's liability to third parties for acts of the pilot, they also may affect the relationships among the pilot, master, and owner. Other commentators (sometimes pilots themselves) describe the pilot as an adviser to the master, although in control of navigation, legal precedents notwithstanding (Ramaswamy and Grabowski, 1992). When the federal pilot of a coastwise vessel is also its master, the question of pilot–master relationship of course does not arise.

Whatever their legal relationship, close cooperation between the master and

BOX 2-5 SOLICITED EXPERT ACCOUNT: PILOT ROUTES PORTS OF KEY WEST AND BOCA GRANDE EDWIN E. CRUSE, IV, *KEY WEST BAR PILOTS*, JULY 1991

Key West

The channel at Key West is 6 miles long. It has four courses and for the most part is 300 feet in width. At the entrance from the Florida Straits, vessels pass through part of the only coral reef in the continental United States. At a point 2.5 miles further, it passes through a secondary coral reef. The sizes of vessels calling at Key West vary from under 200 feet in length and under 3,000 gross tons to over 800 feet in length and over 50,000 gross tons.

Boca Grande

The channel at Port Boca Grande is 5 miles long and has two courses. It has a project depth of 32 feet and a project width of 300 feet. Due to shoaling and infrequent dredging, the allowable draft has been restricted to 24 feet by the pilots. Shoaling has restricted the width to as little as 120 feet in one spot. This situation has to be constantly monitored by the pilots. The size of vessels piloted at Boca Grande varies but since the port now only has one terminal, an oil terminal, the vessels are mostly tows of about 10,000 gross tons. Occasionally ships of about 600 feet in length and 20,000 to 25,000 thousand tons call with partial cargo.

pilot and a proper information exchange when the pilot boards are critical to safe navigation (Bra, 1990; Crenshaw, 1975; MacElrevey, 1988; Meurn, 1990). The master briefs the pilot on the vessel's equipment status, trim,[2] and maneuvering characteristics. The pilot informs the master of plans for the transit. In the case of foreign-flag ships, language barriers may limit this exchange. The pilot also consults the "pilot card" for vessel draft,[3] maneuvering characteristics, and air draft,[4] if available (Bra, 1990; Hederström, 1984, 1989; IMO, 1987). Some vessel operators have established procedures and checklists to enhance this process (Ramaswamy and Grabowski, 1992). Lapses in effective information exchange and passage planning between the master and pilot have contributed to

[2] "Trim" is the difference in forward and after drafts.

[3] "Draft" is the underwater vertical dimension of a vessel measured from the waterline to the lowest immersed part of the hull, usually the keel.

[4] Air draft is the vertical dimension of the vessel measured from the waterline to the highest point of the vessel, usually a mast, derrick, or antenna.

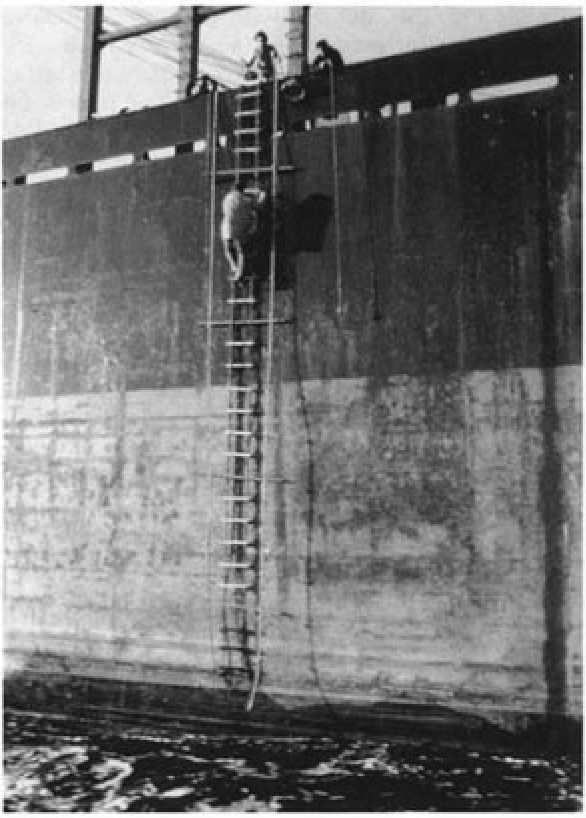
major marine accidents, for example, the 1992 grounding of the *Queen Elizabeth 2* on uncharted rocks near a charted shoal area in Vineyard Sound and the penetration of her hull (NTSB, 1993; USCG, 1993b). Once direction and control is turned over to the pilot, particularly where direction and control is required by pilotage authorities, the master often feels considerable pressure for operational reasons and legal considerations not to countermand the pilot's maneuvering orders. They rarely relieve the pilot. But, many masters do question the pilot about the transit. Exercising command prerogatives is even less frequent aboard many foreign-flag than U.S.-flag ships for reasons including language difficulties, unfamiliarity with local conditions, or limited shiphandling abilities (Ramaswamy and Grabowski, 1992).

There is growing interest in bridge team training (particularly with respect to using computer-based ship bridge simulation) and in bridge resources management training to improve working relationships. Effective bridge team training identifies the appropriate levels of passage planning and interaction between the pilot and the bridge team. Such training, as does passage planning, also can be used to better prepare the master to exercise command responsibility during operations in pilotage waters, including oversight of the pilot. Bridge resources management training, recently endorsed by the American Pilot's Association (PA), focuses on improving interactive skills; this can be done in conjunction with ship bridge simulation training or separately in a classroom setting augmented by interactive, computer-based training devices (PA, 1993; Coning, 1993; Wahren, 1993).

Pilot Responsibilities

Assuming the sufficiency and condition of a ship, its officers, and its crew is a complex issue, but in a broad sense it is the responsibility of the shipowner, the company operating the vessel, and the master. However, the pilot is responsible for safe navigation when exercising direction and control. Therefore, the pilot must be satisfied that the ship can be navigated safely to its destination. The pilot may observe or suspect substandard equipment, maintenance, manning, or maneuvering behavior (such as unexplained sluggish response to maneuvering commands), or the master may wish to conduct a maneuver that the pilot considers unwise. Federal rules require that the person in charge of a vessel notify the Coast Guard of any condition on the vessel that could adversely affect safety or the environment (33 CFR 160); pilot organizations reject the interpretation that pilots are "in charge of a vessel" for purposes of this requirement. There are no state or federal requirements for a pilot to notify safety authorities if there is disagreement between the master and pilot about either maneuvers or the pilot's evaluation of the vessel's ability to safely transit the pilotage route.

Because of increased public concern for public safety and the environment, a few state-level pilotage authorities are beginning to require marine pilots to report substandard or unsafe operating conditions or noncompliance with applicable regulations. For example, state regulations in South Carolina require that state-licensed pilots immediately report hazardous conditions defined in 33 CFR 160 to the Coast Guard (Whitemarsh S. Smith, III, personal communication, July 9, 1991). The Delaware Board of Pilot Commissioners has developed but not implemented a program to report unsafe operating conditions. Some pilots indicated concern that if there were a formal requirement for marine pilots rather than the master to report unsafe conditions, then the marine pilots could be caught between maintaining a working relationship on the vessel and satisfying real-time information needs of marine safety and state-level authorities.



The long climb up the side of a ship in ballast that has not rigged an accommodation ladder. After boarding, the pilot must then proceed to the superstructure containing the navigation bridge, climb to the bridge, meet with the master, and immediately begin piloting. (William F. X. Band, *Association of Maryland Pilots*)

In practice, marine pilots take action when deficiencies directly affect the safety of the vessel or could place their license in jeopardy if a pilot were to provide service while having knowledge of that deficiency. Most often, pilots informally suggest corrective action or alternative maneuvers to the master or recommend that the master report the problem. Some pilots informally or through their association may alert the Coast Guard to potential problems (generally after disembarking). If a serious problem requires action by safety authorities, the pilot could report it immediately, but pilots contacted during the study indicated that this is seldom necessary. Additionally, pilotage administrators contacted by the committee report that most state pilotage systems have stringent reporting requirements for pilots under their licensure should a marine accident or incident of lesser severity occur.

Experienced marine pilots usually have a backup or bail out plan for difficult maneuvering situations that may occur during a transit. These plans are usually informal or intuitive and based on each pilot's accumulated experience. Should an actual emergency occur during transit, marine pilots would possess the shiphandling skills that are necessary for emergency maneuvering, for example, as might be necessitated by loss of propulsion or steering systems, or to react to extreme maneuvering scenarios. Individual capabilities for decision-making under stress have usually been developed through actual service rather than through specialized advance preparation, such as marine simulation training. Difficulties can be encountered when emergencies occur where circumstances provide no bail out options, for example, as might be the case during the transit of a narrow waterway with no anchorage areas or no docks that might support temporary mooring. Difficulties might also be encountered for transits of relatively unchallenging routes if the pilot has not been sufficiently prepared to react effectively to emergencies.

Pilot Compensation

A member of a vessel's crew serving as pilot may receive additional compensation, depending on company policy. Marine pilots, on the other hand, are independent contractors. Billing generally is handled through a pilot association, which serves as an administrative umbrella organization for its members. This approach generally is followed by docking masters as well. Pilotage fees generally are pooled and jointly shared, less expenses, although fees are distributed on a pro rata basis in some associations.

Institutionally, pilotage rates are an element of pilotage administration that can affect, at least indirectly, the availability of pilots as well as safety performance. The financial accountability of pilot organizations that are granted a public franchise to conduct a "limited entry" business is within the scope of this study, insofar as it relates to effectiveness and adequacy of pilotage services and systems. The financial and associated ethical responsibility of marine pilots and docking masters is also within the scope of study insofar as this pertains to the effectiveness and adequacy of pilotage performance (see Appendix D for a related discussion of the Great Lakes Pilot Program). Detailed examination of pilot compensation, however, is outside the scope of this report.

BOX 2-6 SOLICITED EXPERT ACCOUNT: PILOT ROUTES HAWAIIAN PORTS LEONARD A. STENBACK, DAVID B. K. LYMAN, AND JACK ATKINSON, *HAWAII PILOTS ASSOCIATION,* JULY 1991

Oahu Island

Honolulu Harbor is the main commercial hub with the vast majority of the system's vessel traffic. The pilotage route is approximately 3 miles in length. It consists of open ocean, a 500-foot-wide channel cutting through a reef, two 500-foot-wide channels, and two confined turning basins. Berths consist of both narrow slips and marginal piers. Vessel traffic consists of container vessels, passenger vessels, general cargo vessels, oil tankers, tugs and barges, naval vessels, training ships, and fishing vessels. Maximum vessel size handled thus far is approximately 1,000 feet in length with a draft of 38 feet, 6 inches. Controlling depth of the harbor is 40 feet.

Barbers Point Harbor is primarily a bulk cargo vessel and tug and barge port. It also has a small drydock/shipyard facility. The pilotage route is approximately 3 miles in length. It consists of open ocean, a 450-foot-wide channel cutting through a reef, and a confined basin. Berthing consists of a single marginal pier and a small barge pier. The maximum size of vessels handled thus far is 600 feet in length and 33 feet in draft. The controlling depth of the harbor is 38 feet.

Hawaii

Hilo is primarily a bulk cargo vessel, passenger vessel, naval vessel, and tug and barge port. The pilotage route is approximately 3 miles in length. It consists of open ocean, passage through a narrow channel between precipitous cliffs and a breakwater, and a narrow channel passing between a reef and rocks into a confined basin. There is one marginal pier and one finger pier with a barge pier on the other side. The maximum size of vessel handled thus far is 790 feet in length and 32 feet, 6 inches in draft. The controlling depth of the harbor is 35 feet.

Professional Development

Professional development requirements are found in varying degree and adequacy in legislation or regulations for the federal pilotage system, in the pilot age statutes of some coastal states, in the regulations of some local and regional pilotage boards or commissions, or in the policies (formal or informal) of most pilot associations (see Chapter 3). Preparation for obtaining a pilot's license is a personal responsibility. Unless pilot professional development is underwritten or supported by a pilot association or an operating company, an individual must bear the full costs of obtaining the necessary prerequisites for licensing. A substantial personal commitment of time and resources normally is required. *Cost to a pilot candidate is a substantial issue when considering any measure that might be imposed above existing licensing requirements, such as validation of proficiency through actual or simulated marine conditions, to improve or validate the professional qualifications of pilots*.

Many individuals are assisted in developing the knowledge and skills needed to become a pilot. In practice, pilot development responsibilities or support variously falls to the person seeking a pilot's license, operating companies, cognizant pilot associations, or governing authorities. Generally, development programs for marine pilots are left to the discretion of individual marine pilot organizations, including associations of independent federal, state-licensed, and registered (Great Lakes) pilots. This is also the general case for docking master associations and for some operating companies that invest in developing the federal pilotage credentials of vessel officers and mooring masters in their employment (MacElrevey, 1988; Ramaswamy and Grabowski, 1992). Marine pilots and docking masters function as independent contractors, and this status is intended to protect the organizations with which they are affiliated from liability for any deficiency in professional competence (see Parks, 1982).

Development of Federal Pilots

Support for development of federal pilots varies considerably but generally comes from one of three sources, or a combination:

- the individual;
- an operating company; or
- a marine pilot association.

The individual is responsible for obtaining a Coast Guard-issued marine license and for acquiring all basic maritime knowledge and skills that may be required. The federal government and several states operate undergraduate programs to prepare individuals to take the Coast Guard examination for a third mate's license. Several labor unions and at least one private organization also operate maritime training facilities that are used for continuing professional development in the shipping and towing industries. However, there are no programs specifically designed to develop federal pilots except those operated by a small number of marine pilot associations and the Great Lakes Maritime Academy. Knowledge or experience is developed during professional service. Sometimes,

BOX 2-7 SOLICITED EXPERT ACCOUNT: PILOT ROUTE AND SKILL REQUIREMENTS COLUMBIA RIVER BAR AND LOWER COLUMBIA RIVER M. H. DILLON, *COLUMBIA RIVER BAR PILOTS*, OCTOBER 1991

Vulnerabilities and risks associated with vessel operations on the Columbia River Bar and lower Columbia River include weather. Swell and wind-driven seas approaching 30 or more feet meet maximum ebb currents. Vessel considerations for safe transits are draft, maneuverability, horsepower, and freeboard. During commercial and sport fishing seasons, the fish and vessels use the same channel. Commercial gillnets stretch across the navigable channel. Hundreds of small craft extend across the navigable channel during sport fishing season. Anchorage area congestion, berth availability up river, bar closures, the inability of large deep-draft vessels to hold ground during maximum current, and a 600-foot-wide channel are often problems.

Coastwise tanker traffic navigates 30 miles offshore to avoid coastal congestion and fish boat traffic. There is no vessel traffic service. As the vessels approach the pilot station 1 mile northeast of the lighted navigation buoy, the pilot boat suggests courses and speeds to facilitate the orderly flow and proper lee for boarding of a pilot. At times, especially during rough weather, some masters hesitate to approach the pilot station. They lose the coastline in the sea return on radar. The set and drift of the current coupled with the effect of large sea and swell make satellite communication and Loran fixes untimely.

There occurs a distinct switch between "navigating" and "piloting" where constant determination of position with an extremely high order of accuracy becomes mandatory. It reaches a point where failure to anticipate and compensate for the vessel movements can mean an *in extremis* situation with shoal waters, two jetties, and other traffic. The bar pilots' on-station method with the expertise of the pilots has worked successfully without exception.

The pilotage area consists of two distinct grounds: the lighted navigation buoy to Buoy 14 (bar) and the river transit to the Astoria, Tounge Point area. On the bar, I have carried 45 degrees of leeway with engines full ahead making one knot for four hours on an outbound ship. Concerns of bottom clearance, length of vessel in relation to fetch of swells, and ability to maintain maneuverability without damage to deck gear all come into consideration. Inbound riding swells and knowing when to back down the back side of the swell come from experience.

On the river, instant visual and radar position fixing is required, as is sensing ground suction, bank suction, and shear. Set and eddies must be anticipated at different river and tidal stages. Traffic must be anticipated and speed adjusted to avoid close quarters at turns and narrow sections of the channel. At Astoria, background lighting is a problem at night. It is also difficult to acquire jetties visually or with radar at some tidal and river stages. The effects of vessel-induced suction and swell must be considered when passing recreational beaches.

in order to acquire local knowledge of a pilotage route (gauged in terms of "round trips" over that route as an observer under conditions specified by the Coast Guard), an individual seeking a federal pilot endorsement for that route will "observe" the route aboard a vessel of which the individual is not a member of the crew. The provision of such opportunities is not required by federal regulations, and when they occur, they are generally a professional courtesy extended by an operating company.

Some shipping and towing industry companies maintain pilot development programs or policies. These may assist regularly assigned employees in developing the knowledge, service prerequisites, or skills that may be required to:

- obtain a Federal First Class Pilot's License;
- upgrade pilotage endorsements on other Coast Guard-issued marine licenses; or
- serve as a pilot or mooring master aboard company vessels or vessels mooring at a company's offshore facility (in the case of mooring masters) where there are no government-imposed pilotage requirements.

Some shipping companies invest in computer-based ship bridge or manned-model shiphandling simulations. A small but growing number of towing industry companies are investing in computer-based simulations. Such programs are intended to support directly a company's operating, safety, and economic interests. For example, some shipping and coastwise towing companies advised the committee that they encourage masters and mates to obtain a federal pilot's endorsement on their merchant marine licenses for certain routes to permit own-vessel pilotage where federal pilotage is required. In such cases, the services of an independent, federally-licensed marine pilot would not be to satisfy federal regulations. However, some companies advised that their policies authorize masters to take marine pilots in the interests of safety, even if not required to do so by pilotage authorities. The services of marine pilots are routinely being used by some companies to reduce risk even though a master or mate has a federal pilotage endorsement and could legally pilot the vessel. In this regard an increasingly important reason for obtaining a federal pilotage endorsement is to better prepare the master to effectively exercise command responsibility in overseeing the performance of marine pilots, docking masters, and mooring masters (Ramaswamy and Grabowski, 1992).

Development of Marine Pilots and Docking Masters

Development of marine pilots (regardless of licensure) and docking masters, whether in the United States or elsewhere, occurs in three stages:

- acquisition of basic maritime knowledge and skills;
- pilot training (normally an apprenticeship); and

- progressive advancement, once licensed, in the size of vessels to which assigned to provide piloting services.

Many pilot candidates have prior maritime service, including in some cases experience as a federal pilot; other candidates are recruited from maritime academies. In the absence of such background, the marine pilot's skills are built from the ground up by a marine pilot association (Ramaswamy and Grabowski, 1992). This traditional approach is less popular today than it was in the past. Some station boats, on which pilot candidates developed basic maritime expertise as deckhands, mates, and masters, have been replaced by shore stations and all-weather pilot launches. Also, judicious recruitment of individuals with prior experience provides the same basic maritime knowledge and skills. A few associations that do not maintain station boats nevertheless follow the traditional method; they build on the candidate's experience gained in operating pilot launches or while aboard ship during pilot apprenticeships.

Most, if not all, marine pilot associations (including most docking master associations) require an apprenticeship (or indoctrination period). Apprenticeships generally take between a year or less and three years or more. Pilot candidates observed and receive practical instruction on the nature of local routes, ship behavior, and shiphandling skills for a wide variety of vessel types and sizes under widely varying operating conditions. Formal training programs with curricula accredited by the Coast Guard (under 46 CFR 10, Subpart C) have been established by some state pilot associations. One state pilot association maintains a full-time licensed master as a pilot instructor and has a well-developed training curriculum and professional development program (Vincent Black, United Sandy Hook Pilots, personal communication, May 29, 1991). Four other state pilot associations have training programs based on a comprehensive curriculum (Bennett, 1989). However, the majority of associations take a less formal approach, albeit with the same general contents. The emphasis varies considerably by association and operating environment (Ramaswamy and Grabowski, 1992). Theoretical knowledge of ship behavior and shiphandling is taught formally by only a few pilot associations. An increasing number of marine pilots in recent years have taken refresher courses or been exposed to nautical theory through computer-based ship bridge or manned-model shiphandling simulation training. Docking masters report that they learn their trade on-the-job; some have participated in shiphandling simulations supporting waterway design (see NRC, 1992a), but participation in training simulations is rare.

Virtually every development program for marine pilots and docking masters relies extensively on route repetition (the so-called "round trips") to ensure that apprentice pilots acquire essential local knowledge and are exposed to a wide range of operating conditions and ship behaviors. The more trips, the more opportunities to observe and experience the broad range of situations in which the marine pilot is expected to perform perfectly and without hesitation. No one is

BOX 2-8 SOLICITED EXPERT ACCOUNT: PILOT SERVICES AND ROUTES SAN FRANCISCO BAY AREA ARTHUR J. THOMAS, *SAN FRANCISCO BAR PILOTS*, AUGUST 1991

Full piloting services are provided for all vessel types and sizes including tank, dry cargo, and bulk cargo vessels, passenger vessels, tugs with tows, military vessels, and foreign-flag fishing vessels. The largest vessels piloted exceed 1,000 feet in length, 170 feet in beam, and are limited to 50 feet of draft by channel depths. The largest vessel to use pilot services was 265,000 deadweight tons. Piloting services include docking and undocking, routine transit, deadship tow, maneuvering into and out of drydocks, anchoring, and mooring alongside an anchored ship for lightering.

Pilot routes in the Bay Area exceed 200 miles of total length, consisting of open ocean, bar crossing, enclosed bays, sloughs, and an extensive river system. All routes are subject to tidal influences with maximum currents exceeding 7 knots. Channel widths vary from 2,000 feet to 200 feet. There are 10 bridges totaling 17 spans across the navigable channels. Horizontal clearances vary from 97 feet to over 4,000 feet. Vertical clearances (air draft) are as low as 135 feet at mean high water.

The routes begin in the gulf of the Farallon Islands, 11 miles west of the Golden Gate Bridge, and proceed across the San Francisco bar via the main ship channel into the San Francisco bay system. There are more than 25 separate ports with more than 200 individual piers and berths within the system. The longest single route is from sea to the port of Sacramento, a distance of 95 miles.

sure how many trips are needed to ensure such performance, but virtually all marine pilots and docking masters agree that it is a large number and that it should include exposure to the range of operating variables. Trip requirements need to be flexible to accommodate differences in candidates' learning abilities and past experience in the marine environment. State-licensed marine pilots and some federally-licensed marine pilots believe that the number of trips required for a Federal First Class Pilot's License or endorsement—12 to 20—is at best a minimum requirement. One pilot association, by agreement with the Coast Guard as an element of their Coast Guard-approved pilot development program, does not permit a pilot candidate to take an examination for an initial Federal First Class Pilot's License until 360 round trips are accumulated (120 for a third mate oceans license) (Bennett, 1989; Basil R. Watts, Wilmington-Cape Fear Pilots Association, personal communication, December 18, 1991). The Coast Guard accepts the service during the trips as satisfying sea service requirements for an initial license. These trip requirements do not apply to other individuals that might seek an initial federal pilot's license or endorsement for the route. Ultimately, the issue becomes one of the quality of the trips, including training of sufficient duration aboard vessels for which pilotage is sought, not just the quantity (Richard P. Wieners, McCormick Pilot Association, personal communication, July 29, 1991).

Pilots and Modern Technology

Piloting by local experts is heavily dependent on visual cues, particularly for docking and undocking evolutions. However, gyro compasses, rudder angle indicators, radios, radars, and depth sounders are standard equipment, without which few marine pilots will sail. Electronic charts, integrated electronic navigation systems, and automated piloting expert systems (that is, computer-based decision aids) are available but in very limited use. These advances should provide real-time precision navigation and collision avoidance capabilities. System developers state that the objective is to supplement—but not supplant—human

BOX 2-9 SOLICITED EXPERT ACCOUNT: DOCKING MASTER DEVELOPMENT DAVID P. GALMAN, *BOSTON TOWING & TRANSPORTATION COMPANY*, SEPTEMBER 1991

The Boston Towing and Transportation Company's 10-tug fleet serves Boston Harbor and tributary waters of Quincy, Weymouth, and Braintree, as well as Salem (22 miles north of Boston). The passage up the narrow, winding Chelsea Creek is tricky and dangerous, with a 96-foot-wide drawbridge situated between two bends in the river; passing ships reach 661 feet by 90.5 feet, with drafts to 36 feet. Despite the unique hazards of the waterway, the law does not require particular training for negotiating the creek.

Candidates for docking masters must have a background in tug operations and must demonstrate, by actual performance before the three senior pilots, their potential to become good pilots. Candidates must ride on ship docking jobs with one of the experienced pilots, in part to satisfy Coast Guard licensing requirements. Coast Guard minimums "are by no means sufficient for a candidate to start docking ships on his own for our organization. More exposure to the business of ship handling is needed." This is accomplished through personal instruction by—and repeated observation of—senior pilots.

A candidate is given a first job, and later jobs of greater difficulty, when judged ready by the senior pilots. Once a pilot begins solo work, he is observed carefully, both visually and on the VHF radio used to issue commands to the tugs. We are continuously discussing new or unusual conditions encountered, working toward improving our performance, and collectively monitoring the progress of new men as they gain experience docking ships; our customers must be satisfied with our performance, or they will take their business elsewhere, and in today's environment, the customers' ultimate concern is safety.

operators (Grabowski, 1989, 1990). Once the value of specific technology is established, marine pilots frequently become the most ardent supporters and users. If tradition holds, real-time positions derived from electronic charting systems, once the technology is proven, will become as indispensable as radar to the marine pilot.

Over the past decade, technology has been applied effectively by some shipping companies as a means of reducing crew size, so far without apparent reduc

BOX 2-10 SOLICITED EXPERT ACCOUNT: PILOT ROUTE PUGET SOUND MIKLOS ENDRODY, *PUGET SOUND PILOTS,* OCTOBER 1991

An inbound pilotage assignment for a Puget Sound Pilot commences at Port Angeles, whether the vessel is bound for Puget Sound ports or ports in the Rosario Strait, Anacortes, or Bellingham area. The need for pilots to board at Port Angeles is heightened by the fact that an average 15-knot vessel will have transited the Strait of Juan de Fuca for about 4 hours prior to arriving at the pilot station. This transit prior to Port Angeles has increased traffic and the need for the vessel to practice coastal navigation, which, in most cases, means that the master of the vessel is on the bridge or close by. Furthermore, prior to entry into the Strait of Juan de Fuca, it is common for a vessel to have transited the coastal waters of Vancouver island or the state of Washington waters that frequently are encumbered with vessels fishing the several banks there. Added to this scenario are restricted visibility and traffic congestion (due to commercial fishing vessels fishing in the traffic lanes or approaches). The need for a pilot at Port Angeles is vital for a vessel to continue its transit, usually 5 to 9 additional hours, to her port of destination in a safe and timely manner. Puget Sound Pilots perform all piloting functions including the docking and undocking of vessels as part of one normal piloting assignment…

…Considerable barge traffic exists in the area of the traffic lanes, some follow lanes and some do not. Additionally, sport fishing, and pleasure boats as well as sailboat races are common users of the traffic lanes. Washington State Ferry cross traffic is encountered in a vessel's transit to almost all Puget Sound ports. Commercial gillnet fishing in the traffic lanes can present the pilot with the most serious challenge to his piloting and shiphandling skills.

Piloting a vessel to either Rosario Strait or Puget Sound ports is accomplished by the pilot through his familiarity with the area. Piloting by "eye" is essential with some resort to electronic aids, mainly the vessel's radar. A pilot can maintain the vessel's position in the traffic lanes through knowledge of the aids to navigation and experience with wind conditions and tidal currents, which can reach velocities of over 5 knots during certain stages of the tidal cycle. During periods of restricted visibility, a pilot relies mainly on radar to maintain position in the traffic lanes and cognizance of other vessels in his proximity.

BOX 2-11 SOLICITED EXPERT ACCOUNT: PILOT ROUTES SOUTHEASTERN, SOUTHCENTRAL, AND WESTERN ALASKA EDWARD MURPHY, *SOUTHWEST PILOT'S ASSOCIATION*, MARCH 1993

Southeastern Alaska

Southeastern Alaska is about a 110-mile-wide and 300-mile-long strip of mainland and islands. The population of 50,000 is distributed widely in 16 organized coastal communities. Pilots are based principally in Ketchikan, the southernmost city. From this location, pilots board vessels for Ketchikan and points north or they fly out to assignments in the many other communities and small logging ports of the archipelago.

Shipping in this region includes log ships calling at a number of ports and moorings, and ore carriers, which load at Skagway in the north. But the vast majority of the piloting service is provided to several dozen cruise ships that transit the length of the archipelago during the summer, calling at several ports and in Glacier Bay. These ships are underway most of the time, necessitating the assignment of two pilots to stand rotating watches aboard each ship. The seasonal nature of this traffic requires a greatly increased number of pilots for the three-month period. As a result, many of the pilots serving the region work only seasonally. A smaller cadre remains year-round to handle winter shipping.

Piloting along the southeastern Alaska coast is sometimes perilous due to numerous narrow passages that are swept by strong currents, and to the many intense, extratropical low-pressure systems that pass through the region.

Southcentral Alaska

The pilotage region runs from the remote logging port of Icy Bay on the Gulf of Alaska in the south to the fishing and logging ports on Kodiak Island in the west, encompassing Cook Inlet, Prince William Sound, and Resurrection Bay. Pilots are based at Homer, the anchorage area for vessels trading to Cook Inlet. Pilots are dispatched to more than 20 ports throughout the region. Four pilots are also on duty at all times at Valdez to provide service to tankers calling at the Trans-Alaska Pipeline Terminal.

Due to the diverse nature of the region's shipping and environmental extremes, pilots are called upon to exercise a very high degree of shiphandling

tion in safety (NRC, 1990a). The committee heard anecdotal indications that some shipping companies and operators of foreign-flag passengers vessels would prefer expanded opportunities for own-ship pilotage; such a development could potentially reduce operating expenses. Some believe that modern navigation systems and vessel traffic services that permit precision navigation by ships' officers under all conditions could be the means to achieve these ends (see Intertanko, 1990). Shipowners with high-technology ships are interested in obtaining agree skill. In Cook Inlet, crude oil carriers of up to 100,000 deadweight tons are docked and undocked routinely, year-round, without the use of tugs. The strong tidal currents of Cook Inlet and winter ice make the use of conventional tugs at the petroleum terminals impractical. Apprentice pilots are required to become qualified for Cook Inlet operations prior to qualification for service in Valdez.

Piloting in Valdez consists of service to very large crude carriers, with the assistance of three powerful tugs. Pilots serving the Prince William Sound area also are sometimes dispatched for several day assignments aboard cruise vessels during the summer months, usually in the company of another pilot. Other pilot assignments include dispatch to remote ports on Kodiak Island for reefer ships, or to Seward to pilot colliers or small cargo vessels.

Western Alaska

This region covers the rest of coastal Alaska, including the Alaska Peninsula and the Aleutian Islands, where most of the ports are located. The area runs north to Point Barrow and then east to the Alaska-Canada border at Demarcation Point in the Arctic. The region is so large that it has several distinct climates, each of which can be described as generally miserable. The Bering Sea and Bristol Bay ports are subject to persistent fog during the summer months and a continuous series of strong gales during the winter.

The pilots serving western Alaska are based in Dutch Harbor in the Aleutian Islands. It is by far the busiest port in the region and, in terms of fish tonnage, has a very high cargo volume. Pilots handle many small foreign-flag reefer ships as well as large container vessels, which load fish products for the Orient. Pilots also fly out to small, isolated outports and anchorages. They are frequently called on to ride vessels for days, piloting them from port to port.

With the exception of Dutch Harbor, piloting in western Alaska is highly seasonal. The mining port of Kivalina on the Arctic coast, where ore carriers call, is active only from midsummer through September due to the presence of pack ice. During the summer salmon season, ports in Bristol Bay and along the Alaska Peninsula are the scenes of intense, short spurts of shipping activity. Pilots live aboard pilot boats stationed at anchorages and roadsteads, and they handle many ships alongside fish processing vessels.

Western Alaska's huge area; often-grim weather conditions; and small, unimproved ports make the logistics of providing a pilotage service almost as demanding as the piloting itself.

ments from marine pilots for operational practices that would reduce or impose no delays in transit, such as might result from fog, to improve economic efficiency and operational safety (by limiting exposure to adverse operational conditions). *No "system" to date, other than a marine pilot, docking master, or specially qualified master or ships' officer serving as pilot, has been able to provide the expert knowledge of local operating conditions and practices that is essential for safe and efficient transit of pilotage waters.*

PILOTAGE SYSTEMS AND MODELS

The committee's examination of pilotage systems and programs in the United States and overseas uncovered remarkable consistency in key system features. These features seem to the committee to be essential to effective pilotage systems. Comparisons also disclosed several significant areas in which important features vary among systems. The following section summarizes the central features of complete pilotage systems. Each feature is described in Appendix E. Assessment of how existing pilotage systems (regardless of governing authority) reflect these central features is a useful way to pinpoint where improvements could be made to improve individual and system performance. Of particular interest are opportunities for effective introduction and use of new navigation technologies.

The Role of Pilotage Models

Navigation safety depends on effective performance by whoever is piloting each vessel. *The professional discipline needed to achieve effective performance is rooted in the preparations for becoming a pilot, the ability to apply practical skills, the ability to engage in interdependent decision-making on the vessel and in the waterway, and professional integrity*. A pilot must be prepared to work effectively with the expanding range of navigation technologies, amid variability in maintenance conditions, crew performance, and vessel behavior. Various organizational models are used to prepare and motivate pilots to handle these challenges. An effective pilotage model thus becomes an important contributing factor in the effectiveness of piloting. Whether these models (and the associations and governing authorities that employ them) are organized and capable of meeting the challenges of rapidly changing operating trends and technologies are important issues.

Three generic pilotage systems are in use. Pilotage in maritime countries is generally organized around the concept of marine pilots as independent contractors, although there are a few pilot companies and civil service pilotage operations. Administration and governance varies widely within these paradigms. The independent-contractor pilotage model is a convenient way to limit liability to the pilot that provided the service in question, thereby shielding the pilot organization with which the pilot is affiliated. But no model or variation thereof stands out as the most effective or efficient. Indeed, effective pilotage service is provided nationally and internationally in all three basic forms. Even where pilotage models are flawed or have deteriorated in their application, actual piloting services seem in most cases to have remained within expectations of the profession, shipowners or operators, and the public. How well pilots respond to these expectations appears to be the dominant factor in the effectiveness of pilotage, regardless of the pilotage model used.

Central Features of a Complete Pilotage System

Despite the variability among pilotage systems, most have common elements that are universally considered essential for developing and maintaining pilot expertise and system performance (Box 2-12). Central features found in these models in varying degrees are shown. Some of the features are common, some are less common, and others are uncommon. Safety performance monitoring, periodic evaluation of senior or full branch pilots (or their equivalent), and continuing professional development are rare features in both state and federal pilotage systems. It is primarily these gaps that seem to make pilotage most vulnerable for near-term problems in effectiveness and efficiency. In particular, there appears to be significant potential for problems with human performance,

BOX 2-12 CENTRAL FEATURES OF PILOTAGE MODELS

Professional Development
Recruitment
Experience
Knowledge (theoretical, practical, local)
Skills (navigation, piloting, shiphandling, interpersonal)
Continuing professional development
Proficiency validation
Recency
Accountability (professional and official)
Certification/recertification
Licensing
Exemptions
Professional oversight
Audits
Incident/accident investigation
Safety performance monitoring
Discipline
Local involvement
Standards
Administrative standards
Professional standards
Physical condition standards
Organization
Organizational structure (decision-making, business administration)
Infrastructure (vessels, dispatch, administrative offices)

such as development of bad habits or deterioration of skills, which either go undetected or are masked by familiarity with local conditions. Existing pilotage models have not been designed for responsiveness to rapid change in shipping trends and navigation technologies. Consequently, these changes could surpass the capabilities of pilot models.

The pilot model features in Box 2-12 could be used by any pilotage authority, pilot association, or operating company as a functional guide to assess and improve their pilotage programs and practices. The generic model is not meant to suggest that all functions need to be consolidated in a single organization. Some model components might be best accomplished by a pilot association or operating company. Other components may be better suited to administration by a governing authority. Shared responsibility might be best for other components. The model also is not intended to suggest that radical restructuring is necessary or desirable. Dramatic change, in fact, could be counterproductive considering the inherent stability of pilotage services as now structured. This stability is particularly notable amid the dynamic changes that are occurring within marine transportation at large.

Changing Pilotage Systems

Somewhat surprisingly, past changes in the form of pilotage systems (such as from independent contractors to civil service employees), have been motivated by administrative and economic reasons rather than safety performance. For example, in the united Kingdom and the Netherlands, pilotage services were perceived as less than fully responsive to shipping needs, and in the former case, to public expectations as well. Both pilotage systems were modified to improve efficiency, but the countries took opposite approaches. Civil service pilots were reorganized as independent pilots in the Netherlands, while in the United Kingdom, independent marine pilots were reorganized as civil servants (Herberger et al., 1991).

In the United States, the Great Lakes pilotage system was reorganized administratively to improve official oversight and to ensure an effective organizational structure for pilot groups serving the region. Safety performance was not an issue. Responsibility for official oversight was centralized at Coast Guard Headquarters, in Washington, D.C. This action was taken to correct a less-than-independent relationship that had developed between regional administrators and one of the pilot organizations providing service under the system. One pilot organization was dissolved because of financial accountability problems; another was formed in its place to ensure that pilot service would be available (Boyd, 1992a,b,c,d; DOT, 1988, 1990).

3

Pilotage Administration

SUMMARY

Pilotage in the United States serves both state and federal interests. Overall, the pilotage systems exhibit the capability to produce pilots who are professional and competent. However, the current approach is (1) complicated, (2) relies extensively on unpublished professional guidelines and standards, (3) exhibits variability in quality control over professional development, and (4) relies on informal means for detection and correction of weaknesses in individual performance before these deficiencies become causal factors in marine accidents. Jurisdiction is based on factors other than navigation and safety needs. There are no nationally accepted guidelines or baseline standards for the selection, training, licensing, oversight, and discipline of pilots or for the expertise and representation of interests that would assist pilotage boards or government offices in administering official oversight. Such guidelines and standards are essential benchmarks for cognizant pilotage authorities in ensuring the adequacy of federal, state, and local pilotage for vessels in foreign trade as well as coastwise trade. The results are gaps in coverage; continuing controversy over the economics, effectiveness, and accountability of pilotage; and duplication of staff and other costs at federal and state-levels. There are also gaps in official oversight and pilot accountability for harbor transits and docking evolutions involving many ships in foreign trade, although these gaps do not by themselves equate to shortcomings in safety performance.

In general, federal pilotage rules govern the practice of piloting by requiring individuals to acquire licenses to operate certain U.S.-flag vessels in coastwise trade. The federal approach exhibits some important strengths—a nationwide

infrastructure, national policies, well-defined entry-level requirements for sea service and route repetition, consistent licensing and disciplinary processes, and a formal test of knowledge. But federal pilotage also lacks many central features of a comprehensive pilotage system, notably quality control for professional development, tests of practical piloting skills, requirements for emergency shiphandling training or continuing professional development, and official oversight of performance (except for discipline after a marine accident). Federal pilotage rules enable masters and mates to pilot their own vessels. These rules are not directed toward developing pilots as highly skilled, independent professional experts; they are intended to permit pilotage by vessel officers. The system relies on market forces, including the employment, professional development, and assignment practices of employers, to achieve professional competency and proficiency. Masters or mates holding a federal pilotage credential may navigate any coastwise vessel within license limitations under any conditions, regardless of prior service aboard that vessel or vessels of a similar class, the hazards involved, or real recency of service on the route.

States generally regulate the practice of piloting through measures that influence business activities as well as through licensing of individual practitioners; actual measures vary by pilotage jurisdiction. Most state pilotage systems exhibit a broad range of the central features of a comprehensive pilotage system, although none has all these features. There is also great variability in system, content and application of features. A few state pilotage systems lack most of the features necessary to make them comprehensive. While a small number of pilot systems include a formal, rigorous professional development regime, most rely on apprenticeships guided by informal professional development and evaluation criteria to develop necessary theoretical and local knowledge and shiphandling skills. With few exceptions, continuing professional development requirements have not been established, but a growing number of state pilot associations are voluntarily coordinating continuing training opportunities for some members. No state pilotage system has formal requirements for emergency shiphandling training, nor are there formal efforts to detect problems in pilot performance before they become an issue in marine accidents.

There is no quantitative proof of widespread failure of pilots to meet safety standards. The varying completeness in existing federal and state pilotage systems with respect to features associated with a complete pilotage system, coupled with anecdotal evidence, nevertheless reveal opportunities for both local and systemic improvement in pilotage. A new synergism involving both state and federal interests is feasible and essential for improving pilot development, enhancing pilot proficiency, and enabling pilots to perform their critical roles effectively in changing bridge resource conditions. A coordinated approach designed to support pilot performance would enhance the marine pilot's role as an important line of defense against substandard ships, officers, and crews. A national program could be mounted to assist in the consistent application of standards of the profession, enhancing the integrity and accountability of pilotage systems while continuing to provide the span of port-level control that is necessary to accommodate local operating conditions and to effectively oversee provision of pilotage services. The effort could encompass:

- improving public confidence and involvement in pilotage administration;
- assuring jurisdiction over individuals piloting all vessels;
- closing gaps in requirements and accountability in pilotage systems;
- increasing professional development requirements for all pilots;
- establishing a national entry-level standard for all pilots (earned through either an apprentice program or marine service);
- establishing a means to validate professional competence as an element of professional licensing;
- establishing requirements for development of emergency shiphandling skills and continuing professional development;
- consolidating pilotage into a single system for each port region with both local and national oversight; and
- developing organizational structures necessary for effective governance.

INTRODUCTION

With the discussion of piloting practices and the summary of the central features of a complete pilotage system as a backdrop, this chapter examines pilotage administration. The chapter opens with a description and analysis of the professional regulation of pilots. Federal pilotage for coastwise vessels and state pilotage for foreign trade vessels are then assessed by comparison with the complete pilotage model. Coast Guard resources for administering federal pilotage, an issue frequently brought to the committee's attention during the study, are addressed. Pilotage in the coastwise towing industry and pilotage for other categories of commercial vessels are also examined. Lessons derived from reviews of pilotage systems for the Great Lakes, British Columbia, and selected European countries are presented. Finally, alternatives for improving piloting practices and pilotage administration are presented and discussed.

Summaries of professional development requirements are provided in Appendix F. There are no regulations that require pilotage for inland vessels, although their presence in pilotage waters complicates traffic patterns and can be a significant factor in vessel interactions. This is reported in the chapter; however, assessment of the effectiveness of pilotage in the inland navigation system was beyond the scope of this study.

REGULATING PROFESSIONS AND PROFESSIONALS

Professional regulation, as the term is used in this report (see Box 3-1), applies to both the profession and its practitioners. Professions are regulated principally through standards, requirements for licensed personnel to perform certain functions, rates or compensation scales, and other measures. Practitioners are regulated principally through measures, primarily licensing, that authorize an individual to practice a profession or specialty discipline within that profession.

Professional regulation generally is accomplished at the state-level. In the United States, each state has a department responsible for licensing and regulation of certain professions, such as the medical and legal professions. The department may set its own standards, or it may adopt or rely upon accreditation boards or panels operated by professional trade associations that set standards for their profession or specific disciplines. Licensing for tradesmen such as electricians and plumbers typically is accomplished at the municipal level. Not all practicing professionals may be required to obtain a license, but a license may be required to perform certain functions; for example, professional engineers must be licensed to sign and be responsible for construction plans. Generally, regulating business practices is not the responsibility of a licensing department. For example, licensing authorities are normally not involved in rate setting for pro

BOX 3-1 PROFESSIONAL REGULATION AND CERTIFICATION TERMS

Licensing An authorization in the form of a license granted by a government or an entity to perform or provide a function or service. Licensing is rooted in a government's police powers and is applied for the purpose of protecting public health, safety, and welfare.

Registration A listing of an individual or entity with and by some body, governmental or non-governmental. A listing grants no authority nor does it address qualifications.

Certification A voluntary act by an individual and a certifying entity that, in some organized fashion, measures an individual's qualifications to perform a specialized function. No authority or privilege is conveyed, although custom or market forces may necessitate or require that an individual obtain certification.

Accreditation Similar to certification, except applied to institutions, organizations, and programs.

Source: Anderson (1992)

fessions, although this function may be performed by some other governmental entity, such as a rate commission.

Thus, professional regulation ranges from self-regulation to voluntary certification to formal licensing requirements. The full range occurs in piloting, although licensing by some official entity is customary. Where pilotage is required by the federal government, all individuals who pilot vessels are required to hold a license, although not a pilot's license in every instance. Where pilotage is regulated at the state-level, all individuals who provide pilotage services are required to hold a pilot's license.

A license does not ensure that an individual is trained or current in their profession or trade. Its credibility depends on how rigorous the licensing requirement is and what standards are used. However, licensing provides at least one test or filter for competency. An alternative to licensing is professional registration or certification. Sometimes, certification has been used as a means to establish professional standards and requirements for credentials as an intermediate step toward formal professional regulation in the form of licensing (Anderson, 1992). Although certification is by definition voluntary, sometimes possession of a valid certificate or other credential is mandatory for engaging in a profession or obtaining a license. For example, an individual must hold a valid Radar Observer's certificate from a Coast Guard-approved training facility in order to operate inspected vessels of 300 gross tons or more that are radar equipped (46 U.S.C. 15.815). In contrast to broad-based licenses such as those issued for motor vehicle operations, pilot licenses are restricted, with credentials established for specific waterways, routes, and tonnages. The Coast Guard has proposed rules that would establish a similar requirement for automatic radar plotting aids (ARPA)(55 FR 8155).

The effectiveness of certification programs depends on the criteria that the applicant must meet, including expertise, experience, and peer review requirements; the standards upon which the certification is based; and the credibility of the certifying organization. Voluntary certification (or accreditation) does not guarantee professional qualifications or competency. Effectiveness also depends upon the extent to which programs are accepted by practitioners and those they serve. Such programs do, however, indicate that someone or some organization has made an effort to obtain a specialty certification or accreditation and usually that there is a willingness to ascribe to a professional code of ethics (Anderson, 1992).

Airline pilots and mariners are notable exceptions to the state and local control of licensing. Public safety issues and the need to protect the integrity of the national airway system led to the creation of a national licensing program administered by the Federal Aviation Administration. Professional regulation of merchant mariners is a longstanding federal responsibility—except for marine pilots, as described in this chapter. Only the federal government has the mission, resources, and enabling authority needed to administer licensing requirements for masters, mates, and vessel operators. A single federal license (with pilotage endorsements for local waters) precludes the need for multiple state-level licenses. The federal pilot's license for vessels in coastwise trade is based on this concept. There are also federal interests in marine, public, and environmental safety that are served by professional regulation of merchant mariners at the national level.

On the other hand, highly specialized, port-specific pilotage service requires expert knowledge of local operating environments and expert skills in the handling of a wide range of vessel types and sizes. Also, the volume of foreign trade can support only a limited number of local experts. Because of its local nature and the limited economic capacity to support local experts, pilotage fits the framework for professional regulation at the state or local level. The states also have a strong interest in marine, public, and environmental safety, and they are concerned about the economic contributions of waterborne commerce to local and regional economies. These considerations favor professional regulation of pilotage at the state or port level.

Thus, in the United States, there is a dual system of pilotage administration for ports, waterways, and river systems supporting ship navigation, with federal regulation of coastwise pilotage and state regulation of pilotage for vessels in foreign trade. Whether this dual approach adequately satisfies both federal and state interests in marine safety is the focus of this chapter.

FEDERAL REGULATION OF PILOTAGE

Federal Pilotage Requirements

Federal law requires that seagoing vessels in coastwise trade, including self-propelled vessels and tank barges that carry petroleum or hazardous cargoes, must be under the direction and control of a federally-licensed pilot when underway in pilotage waters (46 U.S.C. 8502). Rules issued by the Coast Guard, the administrator of federal pilotage (Box 3-2), interpret this federal law to allow the master or mate of a vessel to act as its pilot if he or she has qualified as a pilot under those rules and has a pilotage endorsement on his or her officer's license. Therefore, owners of coastwise vessels may employ a ship's officer having the appropriate pilotage endorsement to navigate their vessels in pilotage waters. As an individual attached to the vessel and an employee of the shipowner, such an officer has a role that differs considerably from that of a pilot in the traditional sense of an independent expert. Piloting by masters or mates that leads to damage to their or another vessel can result in disciplinary action by their employers, as well as action against their licenses by the Coast Guard. Similar action may be taken if a vessel has been jeopardized without actual damage, if this information finds its way to employers or the Coast Guard.

BOX 3-2 COAST GUARD ROLE IN PILOTAGE

- Determine the minimum qualification requirements necessary to obtain a federal pilot's license and publish federal pilot licensing regulations.
- Interpret federal pilotage statute (46 U.S.C. 8502) and publish regulations regarding which vessels are subject to federal pilotage.
- Interpret the federal pilotage statute (46 U.S.C. 8502) and promulgate regulations regarding where (what waters) federal pilots are required.
- Develop and administer licensing examinations and issue pilot licenses and pilot endorsements to merchant marine or operator licenses held by U.S. mariners.
- Investigate and conduct disciplinary proceedings against federal pilots for violations of pilotage regulations (46 CFR 5.25).
- Conduct port safety and security operations affecting vessel movements, including management of vessel traffic under various enabling authorities.

Partly as a result of increased risk of liability associated with the Oil Pollution Act of 1990 (OPA 90) and other legislation, masters or mates are increasingly less likely to act as pilots of their ships. Some shipping companies encourage their masters and senior mates to obtain federal pilot's endorsements on their licenses to better prepare them to oversee services provided by independent marine pilots. Where pilotage is required in the towing industry, it is usually provided by a master, mate, or licensed operator.

A small number of independent federal pilots—about 30 nationwide—who are neither crew members nor company employees, offer their services locally to guide vessels on the pilotage waters for which they are qualified. They serve coastwise vessels in some mid-Atlantic ports from Maine to Virginia and in the lower Mississippi River. In most of these ports, these federal pilots compete for work with marine pilots from state pilot associations, who virtually all also hold federal licenses. Independent federal pilots are ineligible for foreign trade pilotage, however, because they are unable to obtain state licenses; restrictions in state laws establish pilotage as a controlled-access profession, except in Connecticut. The pilotage system in Connecticut is an open-entry system; the state has initiated steps to overhaul the system.

Federal pilot's licenses or endorsements generally are required by state pilotage authorities or pilot associations as a prerequisite (or evidence of minimum competence) for persons entering state or pilot association training programs, and to meet legal requirements for providing service to coastwise seagoing vessels. In some cases, pilot apprentice programs are designed to satisfy service requirements for original federal pilot's licenses, as discussed later in this chapter.

Waters and Vessels Subject to Federal Pilotage

Coastwise seagoing vessels are required by federal law (46 U.S.C. 8502) to be under the direction and control of a licensed federal pilot at all times when underway in coastal waters and ports within the U.S. territorial sea (seaward to three miles offshore in most locations). Pilotage is required for in-port movements, as from anchorage to dock, as well as during docking and undocking evolutions. This mandate means that the master or a mate, in order to dock or undock the vessel, must hold a federal pilotage credential (license or endorsement) for that route. If neither the master nor mate hold the necessary credential, then an independent marine pilot must be engaged.

Federal pilotage requirements apply to self-propelled vessels and also to tank barges built to carry oil or other hazardous cargoes, provided they are coastwise seagoing vessels. Only about 13 percent of vessels with coastwise routes on their certificates of inspection are tankships or tank barges, although about 80 percent of coastwise cargo tonnage consists of petroleum and petroleum products (MARAD, 1991). U.S.-flag vessels may be documented to engage in both coastwise (sailing under enrollment) and foreign (sailing under registry) trade, but federal pilotage rules apply only when the vessel is engaged in coastwise trade. The trade in which a vessel is engaged depends on cargo and destination rather than vessel flag. For U.S.-flag ships that can serve either trade, the distinction between trades may become blurred because of changes in cargo. The Coast Guard reports that the agency is preparing a Navigation and Vessel Inspection Circular that will provide specific guidance to the marine community and to Coast Guard personnel to assist in distinguishing between foreign and domestic trade.

The definition of "coastwise seagoing" vessels has been controversial in some respects, owing to the limitations and ambiguities of the term. For example, some operating companies have urged that a vessel should be considered "seagoing" and subject to pilotage only if it is actually engaged in a voyage at sea. But the Coast Guard has said a federal pilot is required if the vessel is authorized by its Certificate of Inspection (COI) to go seaward of the boundary line (as defined by 46 CFR 7) regardless of the route of the particular voyage. However, a commercial vessel that is limited by its document to inland routes in bays, lakes, sounds, or rivers, and for which there are no pilotage requirements under present rules, may make extensive voyages between coastal ports—for example, from New York to Boston; from Philadelphia to Norfolk; throughout the Gulf Intercoastal Waterway system; and throughout Puget Sound. The vessel merely has to remain inside the boundary line for the entire voyage.

For tank barges under tow of 10,000 gross tons or less and for small, self-propelled vessels, the Coast Guard has made an exception from the general pilotage requirement (46 CFR 15.812). For these vessels, the master or mate of the vessel or the operator of the towboat may "act as" the pilot if a limited number of additional requirements are met. Under its regulations, the Coast Guard does not supervise compliance with these requirements, but it may call upon these individuals to provide evidence of compliance; generally such requests are made only in connection with an accident investigation. Pilotage in the towing industry is discussed in more detail later in this chapter.

Federal law also authorizes the Coast Guard to require a federally-licensed pilot on any self-propelled vessel engaged in foreign trade in U.S. waters, if (and so long as) state law does not require a state-licensed pilot on the vessel at any time when it is underway in pilotage waters (Box 3-3). Until recently, the Coast Guard has not exercised this authority, although it previously threatened to do so to induce the state of Oregon to impose compulsory pilotage. In July 1993, the Coast Guard proposed rules that would close some existing gaps in state pilotage for foreign trade vessels by requiring a federally-licensed pilot to direct and control the navigation of vessels in foreign trade that operate in certain designated waters of California, Hawaii, Massachusetts, New York, and New Jersey (FR 58[130]:36914-36918). Coast Guard officials have indicated that similar rules may be proposed for California ports where state pilot licenses are not now required.

Even though the Coast Guard does not have pilotage governing authority over vessels in foreign trade (except where a state has not exercised jurisdiction), the Coast Guard can influence its operation. The Coast Guard has substantial

BOX 3-3 GAPS IN OFFICIAL ACCOUNTABILITY FOR FOREIGN TRADE VESSELS

There are five groups of marine pilots in California, 19 East Coast docking master organizations, and a small number of company-employed mooring masters on the California and Gulf Coasts and in Hawaii who hold only federal pilots licenses or endorsements. When bar pilots, harbor pilots, and docking and mooring masters provide piloting, docking, undocking, or mooring services for vessels in the foreign trade and there is no state-level pilotage requirement or credential, these individuals are not serving under the authority of a federal license or endorsement (unless a federal pilotage requirement is established by the Coast Guard in the absence of state action). Thus, for these individuals, there is no official accountability to a licensing authority, although some measure of professional accountability may accrue through various market forces. The lack of official accountability has received considerable public attention in some areas, typically following marine casualties that resulted in or had a high potential for pollution. Coast Guard rulemaking to close some of these gaps is in progress.

Sources: Crowley, 1991; FR 58[130]:36914-36918; Journal of Commerce, 1992b; Parks, 1982; Ramaswamy and Grabowski, 1992; USCG, 1990a.

authority, for example, under the Ports and Waterways Safety Act of 1972, as amended, to issue mandatory orders to all vessels concerning movement and operating conditions.

Federal Licensing Requirements

The Coast Guard is required by law to ensure that federal pilots have and maintain adequate knowledge and experience for the waters and vessels on which they are authorized to serve. To help meet this obligation, the Coast Guard has extensive power to regulate the licensing of federal pilots.

Under present regulations, an applicant must pass an examination after at least 36 months' service on board a vessel or vessels, including three months within the preceding three years, and at least 12 months operating on the class of waters for which pilotage is desired such as rivers, canals, or inland waters. Practical training in an apprenticeship program approved by the Coast Guard may be substituted for some or all of the required service. The pilot candidate must also have a Radar Observer's Certificate. The candidate must have completed 12 to 20 round trips over the route sought to obtain an "original" license, the first marine license that is issued to an individual. A candidate already holding a marine license must complete 8 to 15 round trips for a pilotage route endorsement on that license.

Pilot candidates, including those already holding marine licenses, are not required to have experience conning a vessel, to have any prior service or training as a pilot (unless in a Coast Guard-approved pilot apprenticeship program), or to demonstrate competence or proficiency as a pilot. Extra requirements for a

BOX 3-4 CHARACTERISTICS OF A FEDERAL PILOT AS A MEMBER OF A VESSEL'S CREW

- Licensed by the Coast Guard.
- Provides pilotage services to U.S.-flag vessels in domestic trade.
- Employee of a shipping company.
- Member of the regular complement of the vessel's crew, serving as master or mate (that is, not independent of the vessel).
- Knows the specific vessel and its operating characteristics.
- Works with other Coast Guard-licensed officers aboard the same vessel.
- Knows the capabilities of the other members of the vessel's crew, both licensed and unlicensed.
- Normally works with individuals who speak and understand the English language.
- Accountable to the Coast Guard as licensing authority.

specific port may be set by the local Coast Guard Officer in Charge of Marine Inspection (OCMI), but this is seldom done.

That existing federal pilotage requirements represent entry-level criteria is widely recognized by marine pilots, docking masters, other mariners, shipping companies, and the towing industry. In practice, mariners seeking federal pilotage credentials generally already have a marine license, and, by virtue of licensing criteria, practical experience. A deck officer aboard an oceangoing ship, for example, typically will have graduated from a maritime college and will have accumulated several years of nautical experience before qualifying for a pilotage endorsement. The more senior the marine license held, the more experience will have been accumulated. Many mariners seeking pilotage credentials are either masters or hold licenses as masters. Although a licensed operator of an uninspected towing industry vessel might have different service than a ship's deck officer when qualifying for pilotage of tank barges, much of this experience will have been gained in pilotage waters due to the nature of coastwise towing industry operations.

The Coast Guard has approved 10 apprentice pilot programs run by state pilot associations as satisfying the requirements necessary to obtain an original Federal First Class Pilots License. The programs were developed by the associations and submitted to the Coast Guard for approval. All are at least three-year programs. Round trip requirements vary from 40 to 360. For example, 360 round trips are required by the Wilmington-Cape Fear Pilots for its apprentices before they can be examined for an original Federal First Class Pilot's License (Bennett, 1989).

Under federal law, the Coast Guard may classify licenses by tonnage of vessels, waters traversed, and other standards. Present Coast Guard regulations strictly conform to the provisions of the International Maritime Organization (IMO) Convention on Standards of Training, Certification, and Watchkeeping (STCW) for masters and mates (IMO, 1978, 1991). A master's or mate's license is granted for vessels of any type or gross tons based on service on self-propelled vessels of 1,600 gross tons or greater. The STCW standards do not provide parallel language for pilots. Because federal pilotage is directed principally toward deck officers rather than independent pilots, and in the absence of specific IMO guidance relative to vessel size, the Coast Guard applies STCW tonnage provisions to pilotage on all self-propelled coastwise vessels. An OCMI can issue a first class pilot's license restricted to a class of vessel, such as tug and barge combinations, which is the most typical case.

To keep a license in effect, a federal pilot must make one "refamiliarization" round trip every five years over the licensed route. In the case of long routes, the pilot need only review charts and other materials. The license is granted for a term of five years. It may be renewed by mail upon evidence of one year of sea service in the past five years. There are no requirements for periodic review or oversight of the skills and competence of federal pilots or for periodic refresher training. The committee could not identify data that could be used to link the minimum requirements to actual pilot performance.

BOX 3-5 CHARACTERISTICS OF A FEDERAL PILOT NOT A MEMBER OF A VESSEL'S CREW

- Licensed by Coast Guard.
- Independent of the vessel piloted (not a member of the vessel's crew).
- Independent contractor.
- Member of an independent pilot association.
- Provides pilotage services to U.S.-flag vessels in domestic trade.
- Familiar with a range of vessel types and maneuvering characteristics; often has prior experience aboard the vessel piloted.
- Works with merchant marine officers licensed by the Coast Guard.
- Works with individuals that speak and understand the English language.
- Accountable to the Coast Guard as licensing authority.
- Participates in a pilotage business that typically includes:
  - — articles of association;
  - — working rules and dispatch procedures;
  - — maintaining a pilot office;
  - — incurring debt and paying creditors and employees;
  - — operating a dispatch service;
  - — operating pilot boats or launches;
  - — participating in a pilotage rotation system;
  - — billing and collecting for pilotage services;
  - — determining pilot numbers (sometimes set by governing authorities);
  - — setting and negotiating pilotage rates;
  - — controlling pilotage expenses; and
  - — operating a pilot training program for new members.

These characteristics may vary somewhat. For example, one major tanker operator hires its own federal pilots to board its coastwise ships and serve as pilots in federal pilotage waters; these individuals are employees of the operator, although not members of a vessel's crew.

Existing federal requirements do not address substantial differences in the behavior of various types and sizes of vessels under differing operating conditions (see Chapter 4). Yet pilots face daily and seasonal variations in traffic and weather; vastly different day and night conditions; and, in river systems, different river stages. Some owners and operators of coastwise seagoing vessels reported to the committee that they have significantly increased standards for their ships' officers who, if they hold pilotage endorsements, may serve as pilots on their vessels. Similarly, associations of independent federal pilots and some dock ing masters reported to the committee that they have raised professional standards for their members significantly above minimum requirements for federal pilot's licenses or endorsements. The higher standards required by these owners and associations cast doubt on the adequacy of the federal requirements.

Federal Pilot Examinations

To obtain an original Federal First Class Pilot's License (or First Class Pilot's endorsement to a license as master, mate, or operator), a candidate must fulfill all the aforementioned requirements and must pass a written examination. The examination covers knowledge of navigation rules, pilot rules, use of tide and current charts, winds and weather, chart navigation, aids to navigation, shiphandling, pollution prevention and abatement, Captain of the Port regulations and vessel traffic service (VTS) procedures, and other subjects directed by the cognizant OCMI. Also required is a chart sketch of the route demonstrating knowledge of recommended courses, distances, prominent aids to navigation, depths in channels and over shoals, and other important features of the route. To obtain a route-extension endorsement, the pilot must make a prescribed number of round trips on the route, passing an abbreviated examination, and draw a chart of the route.

Official Discipline Under the Federal Pilotage System

There are two forms of discipline—professional and official (the latter is usually related to a marine incident or accident). Professional discipline—the ability to act in accordance with the rules or standards of the profession—is developed through pilot apprenticeships and continuing professional training (Chapters 2 and 7; Appendices E and F). Good professional discipline is one important defense against deficient performance, mitigating the need for official discipline.

Complete pilotage systems, as envisioned by the committee, include specific programs designed to detect shortcomings in knowledge or skills of licensed pilots prior to accidents, although an official disciplinary process is also an important feature. Advance detection programs are not features of either federal or state pilotage. When an incident or accident occurs, cognizant Coast Guard officials focus on establishing the facts to determine what, if any, corrective or punitive action is indicated by the agency. Failure of propulsion or steering systems, rather than pilot error, for example, could be the cause of a grounding.

Under the federal pilotage system, the Coast Guard can revoke or suspend a pilot's license if the pilot violates any law intended to promote marine safety or to protect navigable waters, commits an act of misconduct or negligence, or becomes incompetent. Such action may be taken, however, only if the pilot is acting under the authority of the federal license. That is, the Coast Guard may not revoke or suspend the federal license of a pilot who is guilty of faulty work while piloting a vessel in foreign trade under the authority of a state license. The Coast Guard may assess other penalties if other federal laws or regulations are violated. The limits of the Coast Guard's jurisdiction in these matters were defined by the courts in 1974. Following a grounding attributed to a vessel's state-licensed pilot, the Coast Guard took action against that pilot's federal license, claiming jurisdiction because the federal license was required by the state as a prerequisite for service as a state-licensed pilot. The Coast Guard action was overturned on the grounds that the pilot was serving under the terms of his state license at the time of the grounding, and there was no requirement for federal pilotage (Parks, 1982).

The Coast Guard is able to take action against any federal pilot's license or endorsement if the pilot fails a mandatory random drug test (drug-free status is a condition of holding the license or endorsement). The Coast Guard also administers a federal requirement for mandatory substance-abuse testing following a marine casualty. Depending on the nature of an incident as determined by an investigation, a pilot may be disciplined by a letter of warning, a fine, or a reprimand; in serious cases, the pilot's license may be suspended or revoked. Civil or criminal prosecution can be initiated in severe cases, such as willful misconduct.

Federal disciplinary proceedings can take up to several years—longer if legal challenges are mounted. However, a somewhat shorter time frame is common. If a federal pilot's license or endorsement is suspended during the proceedings, then the individual usually has limited opportunities to continue work in the maritime field pending completion of disciplinary proceedings and assessment of any penalties. Considering the time frame required to qualify as either a federally or state-licensed pilot, such disciplinary processes could affect the availability of qualified pilots in areas with small pilot services. More expeditious proceedings would be desirable, insofar as their thoroughness could be assured.

Coast Guard Resources for Overseeing Pilotage

While pilots must be qualified for the service they provide, so too must those who administer pilotage (whether federal or state), to ensure that a sufficient expertise is available for setting pilotage program requirements and effectively administering them. The Coast Guard provides administrative and operational oversight because of the agency's major port and navigation safety responsibilities. There are no national or international standards for the qualifications of pilotage administrators, but maritime experience and piloting expertise are considered highly desirable assets for overseeing the complex nature of pilotage. A concern frequently expressed to the committee is that the Coast Guard may not have sufficient resident expertise to set qualifications for pilotage (Ashe, 1984); to establish locally specific route-familiarization requirements; or to perform waterways management activities, such as VTS operations, which directly or indirectly influence pilotage.

The Coast Guard's multimission responsibilities provide for extensive regulatory authority. The agency's infrastructure is designed to administer national regulatory systems, including federal pilotage. The Coast Guard enforces regulations related to port safety and security, in the process taking actions that directly affect marine navigation and piloting, as well as marine environmental protection. These activities are performed to the limit of available resources. The Coast Guard has considerable experience in pilotage administration and has the capability to take strong corrective action where specific problems have been identified, as reflected in agency efforts to improve administration of the Great Lakes pilotage system (Appendix D). However, the agency has limited capability to build hands-on experience in the piloting of commercial vessels. The Coast Guard operates few vessels that closely resemble commercial vessels in handling characteristics. Nevertheless, deck service aboard Coast Guard cutters can provide hands-on piloting opportunities, allowing some coastguardsmen to build considerable practical knowledge of vessel behavior as well as shiphandling skills.

Although merchant marine licenses are not required for Coast Guard service and only a small number of coastguardsmen hold them, considerable merchant marine and sea-service expertise generally is available within the marine licensing program. For example, of 36 professional program personnel (military and civilian) in the Merchant Vessel Personnel Division, U.S. Coast Guard Headquarters (the office that oversees marine licensing, including federal and Great Lakes pilotage), 23 hold merchant marine licenses or have qualified as deck or engineering watch officers on Coast Guard vessels (Figure 3-1). Of these, 30 percent have more than 10 years sea service. The Coast Guard does not maintain information about merchant marine licenses held by personnel assigned to the 17 regional examination centers, marine safety and Captain of the Port (COTP) offices, and vessel traffic services. The agency reports that sea-service backgrounds are considered in assigning personnel to marine and navigation safety duties as well as in the hiring of civilian personnel (licenses cannot be specifically required under federal recruiting rules unless, for example, a license is required by law or regulation). In the committee's experience, agency personnel holding merchant marine licenses and having marine licensing responsibilities are more prevalent on the Headquarters staff than in the field.

At the port level, knowledge of commercial vessel navigation and piloting varies among individuals performing COTP functions, including VTS operations. At this level, sea-service experience generally has been gained aboard Coast Guard cutters or brought into the agency through recruiting programs that target individuals with merchant marine backgrounds. Some years ago, the Coast Guard recruited licensed merchant marine officers into its commissioned officer corps at mid-grade levels to ensure that the agency would have the necessary expertise to conduct its marine safety program. Present Coast Guard efforts to ensure the availability of essential merchant marine expertise and to maintain close ties with the merchant marine industry include several important programs (Kime, 1992). The Coast Guard sends recruiters to the six state maritime academies at least once a year. Graduates are recruited into the officer corps through the Maritime Graduate (MARGRAD) program; undergraduates are recruited under the Maritime Training Program (MARTP). At this writing, 14 graduates and 30 undergraduates are being recruited each year. The Coast Guard plans to increase these numbers to approximately 20 graduates and 90 undergraduates. By comparison, the U.S. Coast Guard Academy graduates and commissions approximately 200 officers each year (J. F. McGowan, U.S. Coast Guard, personal communication, January 26, 1993).

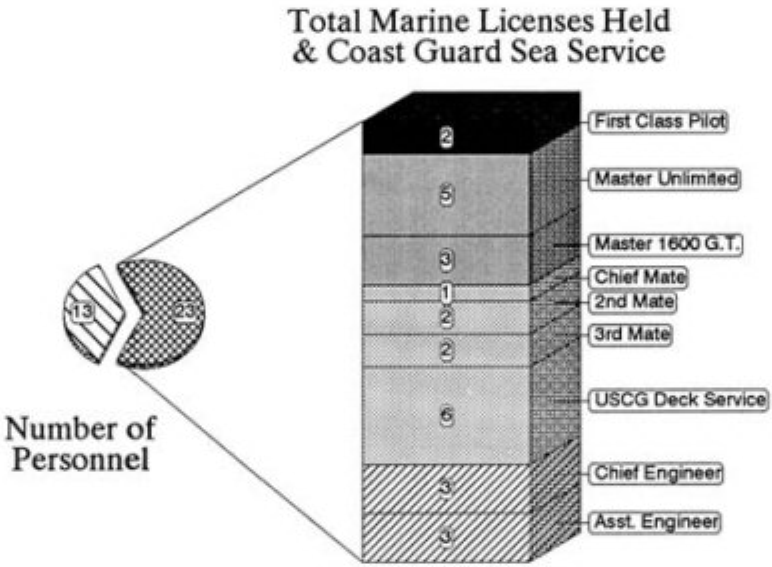


FIGURE 3-1 Maritime credentials for 23 of 36 coastguardsmen and civilian employees serving in the Merchant Vessel Personnel division, U.S. Coast Guard Headquarters, Washington, D.C., March 1993.

The Coast Guard also sponsors a program in which about four officers train with the marine industry each year. The selected officers are "loaned" to private companies or port authorities for up to a year so they can build familiarity with commercial vessel operations and management. Still other coastguardsmen have opportunities to build knowledge of commercial vessel operations, including marine pilotage, through assignments to VTS and commercial vessel rides that are part of Coast Guard VTS training (Ives et al., 1992).

The committee did not have sufficient information to determine the nationwide distribution of Coast Guard uniformed and civilian personnel with merchant marine licenses and sea-service experience or to ascertain the effectiveness of training opportunities in building the expertise essential to pilotage administration and operational oversight. As the preceding discussion indicates, the Coast Guard may have more merchant marine and sea-service expertise within its ranks than typically is perceived by the maritime community, although it may be difficult for personnel to achieve the same depth of expertise as found among those who routinely serve aboard ship or in the towing industry.

Assessment of Federal Pilotage

Federal pilotage establishes a national baseline for the general marine experience and basic knowledge of local routes needed by pilots (see Fugaro, 1976). The federal rules have been adopted as entry-level requirements for state pilot and docking master trainees and thus have become de facto national standards for this limited purpose. Although the federal system requires route repetition (that is, round trips), it does not establish pilot training requirements, and it does not provide quality control over professional development or practices that would provide a national standard for piloting skills. The development of piloting skills, professional competence, and proficiency thus depends upon the efforts of individuals, operating companies, and marine pilot associations. The federal disciplinary process is consistent nationally, but there are no provisions for detecting and correcting shortcomings in human performance before they result in incidents or marine accidents.

Existing federal pilotage rules, if retained in their present form, would permit less rigorous pilotage competency requirements than those envisioned by the committee as central features of a comprehensive pilotage system (Appendix E). Moreover, the federal approach, by broadly enabling ship's officers to serve as a vessel's pilot, does not reflect the traditional concept of the pilot as an independent professional expert. Because the federal system lacks provisions for quality control and validation of experience and skills, federal pilot's licenses and endorsements do not by themselves ensure professional competence or proficiency. The use of round trips as the principal criteria for pilotage route endorsements does not take into account important variations in operating conditions, maneuvering characteristics of different categories or sizes of vessels, or pilot background and skills. Thus, a licensed federal pilot may serve a broad range of vessels under all conditions, without specifically relevant training or experience. While the Coast Guard has authority to recognize differences in the degree of hazard posed by various vessel types, cargoes, and operating environments, this authority is not exercised to any significant extent. The recency requirements for maintenance of a license or endorsement do not ensure sharp skills. Other than random testing and record checks for alcohol and substance abuse during the licensing process, pilot assessments and corrective or disciplinary actions are not carried out until after an accident occurs. Finally, there are no data that establish statistically the effectiveness of official discipline under federal pilotage in terms of systemic changes in safety performance.

STATE REGULATION OF PILOTAGE

State Pilotage Requirements

Under present federal laws, the coastal states (except those on the Great Lakes) are free to regulate pilotage on vessels in foreign trade, including foreign-flag and U.S.-flag vessels, entering, leaving, or otherwise moving within their ports and waters. Although regulations vary from state to state, all seaboard states require vessels in foreign trade to employ state-licensed pilots while entering or leaving all major ports, with the exception of some California ports as noted in the next paragraph. (In some states, pilotage laws allow a vessel to refuse pilot services, although they still have to pay all or a specified portion of the pilotage fee, but this alternative is almost never chosen.) Many states also require a licensed pilot for movements within a port. No state requires that a pilot actually conduct docking or undocking maneuvers, but some states require the presence of the pilot on the bridge during these evolutions. On the West Coast and Gulf Coast (except for Mobile, Alabama), marine pilots customarily handle all docking. Marine pilots provide these services at the master's request. No state (or the Coast Guard) currently licenses individuals solely as docking masters (Ashe, 1984; Crowley, 1991; Parks, 1982, 1988), although civil service pilots in Mobile, Alabama, who are employed by the state port authority, conduct intraport movements and provide docking services to ships in foreign trade under the authority of state pilot licenses.

In California ports outside the San Francisco Bay area, state-licensed pilots are currently not required by state law for foreign trade vessels although state law authorizes local pilotage regulation. In Los Angeles, pilots of vessels in foreign trade are municipal employees; each holds only a federal pilot's license. In Long Beach, pilot services are provided under a contract between port authorities and an employee-owned company, which trains and employs the pilots (all of whom hold federal licenses). In San Diego, a local pilot association is commissioned by port authorities to provide pilot service, but individual pilots (all of whom hold federal licenses) are not licensed individually by the port. In some other California ports, marine pilots serving vessels in foreign trade have not been regulated by any official bodies, although their associations are seeking official recognition and oversight. Pilotage in California is undergoing extensive examination by state authorities (OSPR, 1993, 1994).

In general, state-licensed pilots are required by their state (or governing board, commission, or port authority) to obtain federal pilot's licenses or en dorsements before or during state and local training and apprenticeships. Therefore, state-licensed pilots are eligible to serve vessels in coastwise as well as foreign trade, although on any given transit, they act under the authority of only one license (Parks, 1982). In the past, they generally were not hired by coastwise vessels unless the master or other ship's officer did not hold the required federal license or endorsement, although masters sometimes took a pilot as a safety precaution. This latter practice is generally permitted by the policies of shipping companies in the coastwise trade. However, because of heightened awareness of the consequences of mishaps or accidents, use of marine pilots for port entry and departure has become increasingly common for coastwise ships, especially tankers, as a means of supplementing onboard shiphandling expertise and local knowledge. In some state pilotage jurisdictions, such as in Texas, the loss of the federal license places a state license in jeopardy as well (Ramaswamy and Grabowski, 1992).

BOX 3-6 CHARACTERISTICS OF STATE PILOTS

- Licensed by coastal states or local pilotage commissions or boards provided for in state legislation.
- Independent of the vessel piloted (not a member of the vessel's crew).
- Independent contractor.
- Member of an independent pilot association.
- Provides pilotage services to vessels in foreign trade, mostly foreign-flag vessels.
- Familiar with a wide range of vessel types and maneuvering characteristics; often no prior experience aboard the vessel piloted.
- Works with merchant marine officers licensed by other flag-states.
- Works with individuals that may not speak or understand English.
- Accountable to a state licensing authority or local commission or board in most pilotage jurisdictions.
- Operates a pilot business.

State-Level Resources for Administering Pilotage

Generally, few resources are directed to pilotage administration at the state or local level. Extensive state and local resources are not used because most pilots operate self-supporting businesses that conduct the bulk of system administration, such as the scheduling and dispatch of pilots. Further, the number of individuals that are regulated in each port or state is small and therefore does not necessitate a large regulatory infrastructure to provide official oversight. This is in contrast to federal pilotage which is a nationwide program with centralized regional administration. While a few states have small departments that regulate pilotage, most rely on pilotage commissions and boards. Typically, commission or board members serve part-time and are supported by a small professional staff, usually only several individuals. Generally, but not always, the members have maritime and pilotage expertise. Individuals serving on pilotage boards and commissions generally have extensive professional backgrounds. Those with maritime expertise generally are senior mariners with federal or state pilotage credentials, or both. In some cases, members of a port commission also have responsibilities for pilotage oversight, normally in addition to other responsibilities. The duties of pilotage commissions and boards are generally limited to professional regulation including training requirements, discipline, and in some cases, rate setting.

State Pilotage Boards

State laws generally provide for state or local pilotage boards or commissions, which establish pilotage regulations for vessels in state waters; set standards for selecting and training pilot applicants; grant licenses; and oversee and discipline pilots. Pilotage fees are set by statute, by pilotage boards, or by other regulatory or legal bodies. The terms of these laws and regulations and the manner in which state boards perform their functions vary considerably and have generated controversy (see Crowley, 1991; NTSB, 1988a; Wastler, 1992b, 1993a,b). Some states allow or require the appointment of active marine pilots to the board, while some require appointment of members of the public. Other states prohibit marine pilots from serving on the board (Ashe, 1984; Crowley, 1991).

State Pilot Associations

In nearly all ports, the state pilots serving the port are members of a pilot association. The association (or a pilot-owned company or corporation) provides equipment and services in support of the pilot's work. Support includes pilot boats; dispatch services; accounting and financial services; representation in dealing with government, shipowners, and others; and in one port where there previously were no tugboat companies, provision of tug assist services using the pilot boat. Infrastructure needs make it impractical for a pilot to operate effectively without the backing of an association in a large port, although small-scale pilot operations are available in some small ports. Generally, the pilot associations also are responsible for the recruitment, training, and evaluation of pilot applicants and have a role in oversight and discipline, subject to the authority of state or local boards. Pilot associations are therefore vitally important elements of the state pilotage systems.

In some states, the role of the pilot association is recognized by law, and the association may be considered a quasi-governmental organization. Access to the pilot profession is limited or controlled by the state or local pilotage authority to ensure adequate pilot qualification and that the pool of pilots does not exceed the number that can be reasonably supported by the net income generated from services provided to foreign trade vessels. According to state pilots, limited access also prevents unsafe competition between pilot associations and averts pressures from vessel operators that might place economic or other considerations over safety performance (Crowley, 1991; Journal of Commerce, 1992b; Robson, 1990).

But some sectors of the marine community, particularly shipping companies and independent marine pilots, argue that competition is not the problem. Independent federal pilots describe their professional credentials and performance as equivalent to that of state-licensed pilots (Robson, 1990). Shipping companies typically believe they should have a voice in who pilots their vessels, considering the potential economic consequences if pilot error leads to a marine casualty (Ramaswamy and Grabowski, 1992). These groups assert that the link between competition and unsafe operating practices is not supported by analysis of safety data (see Booz, Allen and Hamilton, 1991). Further, some state pilot associations compete with each other, and others compete with independent federal pilots for pilotage of vessels in the coastwise trade and government vessels.

Usually, there is only one association for each port or pilotage area. However, in Alaska, Florida, Hawaii, and Oregon, economic factors resulted in the formation of competing state pilot associations (Dexheimer, 1991). There also was a recent unsuccessful attempt to form separate pilot associations for several San Francisco area ports (Wastler, 1992b, 1993a,b). These developments generally have resulted from disagreements over association financial matters such as pilot compensation and pension plans. Formation of competing associations is not addressed or prohibited by many state pilotage laws and regulations.

State-licensed pilots may, and in a few ports do, compete for non-foreign piloting business, such as U.S. Navy ships and commercial ships in domestic trade, that by law, regulation, or contract, requires federal pilots. Marine pilots holding only federal licenses are prohibited by state laws from competing for business reserved for state-licensed pilots. Competition introduces new complexity into debates over economic and safety issues, confounding any resolution.

Training and Professional Development

Recruitment, training, and development requirements for state-licensed pilots generally are set by state-level governing authorities; implementation normally is conducted by or through the pilot associations. In most states, after an applicant is accepted for training, he or she enters a pilot apprenticeship program. The apprentice receives practical instruction from senior pilots in piloting skills, characteristics of the route, and ship behavior for various vessel types and sizes and operating conditions. The apprentice must complete the number of trips established by the governing authority for the route and waters on which the candidate will serve, as a prerequisite for examination and licensing. As part of training, the apprentice generally is required to obtain a federal pilot's license (or endorsement) for the same routes and waters.

After licensing, most state systems require substantial service over a period of years on vessels of small and moderate size before a pilot is allowed to serve large ships. Some states require the pilot to pass another examination before advancing, but generally, progression depends on experience rather than formal assessment. Further formal training or development and professional evaluation typically are not required, except for occasional refresher training for pilots who have been out of service for an extended period. Once a pilot is fully qualified, performance monitoring is generally informal and ad hoc. Pilots generally have been reluctant to address colleague performance because of social and business relationships, potential loss of earning for affected individuals, and especially concern that any form of oversight might expose them to liability for a colleague's performance. Systematic means for advance detection of degraded skills or other factors that could adversely affect performance are generally not available to assist in determining needs for remedial action. In a few state systems, such as the Florida state-wide system, continuing professional development requirements have recently been instituted. A growing number of pilot associations voluntarily have begun to send some members to shiphandling simulation training as one element of association professional development programs. Some of the simulations are generic and focused on skill development; others are specifically tailored to the vessels and routes served. Marine pilots use simulation as a supplement to actual experience and training gained through apprentice programs. Similarly, the American Pilot's Association recently endorsed participation in bridge resources management training by its membership as an additional means to enhance pilot performance (APA, 1993).

Pilot Discipline and Operational Oversight Under State Systems

Various oversight and disciplinary processes are used in the state systems. Critics of safety performance have questioned whether these measures are adequate in all states to screen out pilots with unsatisfactory records (Ashe, 1984; Crowley, 1991; NTSB, 1988a; Parker, 1988). Although auditing the disciplinary record of state pilot systems was outside the scope of this report, the committee was able to make some observations. What emerges from the available evidence is a range of response to safety issues.

State pilotage system authorities may discipline a pilot by assessing fines, suspending or revoking the pilot's license, lowering the pilot's grade, placing the pilot on probation, or other measures (Ramaswamy and Grabowski, 1992). As early as 1983 (in Louisiana), random alcohol and drug testing programs began to appear at the state-level, and they have been successful in detecting and screening out abusers, including active pilots. Some pilot boards conduct post-incident tests for drugs and alcohol (Michael Delesdernier, attorney-at-law, personal communication, January 17, 1992; Gary Maddox, Tampa Bay Pilot's Association, personal communication, January 17, 1992). Investigative procedures following an incident or accident vary considerably. Some boards rely on Coast Guard investigations. Others conduct on-scene or full-scale investigations.

State influence over commercial vessel operations is indirect, in that the states cannot direct or limit the operations as can the Coast Guard. But states can and do establish requirements for pilotage; some have established ancillary requirements, such as tug escorts for tankers and, in the case of Washington State, requirements for a person fluent in English to be on a tanker's bridge. Thus, while the states cannot direct operations, they can control some of the rules and have direct influence over the professional development of some of the players. The *Exxon Valdez* grounding spurred states to tighten controls on marine safety (Crowley, 1991; Sankovitch, 1993). For example, strong legislation establishing public oversight of marine safety, complementing existing pilotage oversight, was enacted in the state of Washington (Darlene Maddenwald, Washington Environmental Council, personal communication, October 7, 1991). Several other states also have enacted legislation affecting the carriage of petroleum that also may influence pilotage practices.

The NTSB has been critical of the integrity of state pilot systems. Following its examination of a marine casualty in Louisiana, the board found what it considered to be system faults within state pilotage systems nationally. In the Louisiana case, the board found that the pilot governing board, composed entirely of pilots from the association governed, was unable to provide independent oversight, with the result that discipline was inadequate for pilots involved in marine casualties (NTSB, 1988a). The Louisiana Legislature, at the urging of local pilot associations, responded to the board's criticism and passed legislation requiring establishment of pilot review boards to oversee the performance of the existing boards of pilot examiners. The five-member pilot review boards each include two nonmaritime public members appointed by the governor. This requirement is being implemented (Michael Delesdernier, personal communication, January 17, 1992).

The NTSB also recommended that the federal pilot's license be established as superior to state pilot's licenses so that Coast Guard discipline could be applied to all pilots, regardless of what licenses they operate under (NTSB, 1988a). However, the NTSB report provides only a cursory examination of other state pilotage systems and federal pilotage, including official discipline (see Ashe, 1984). Therefore, the board's recommendation has been the subject of considerable controversy.

Assessment of State Pilotage Systems

The structure and administration of state pilotage vary widely among the coastal states. Although most programs have very similar primary components, there are no national guidelines or incentives to motivate consistency in basic system requirements or their application as the foundation for locally-specific requirements for pilot qualification and performance, nor are pilotage systems accredited by any nationally accepted body to enhance public confidence in their ability to satisfy both state and federal interest in safe navigation. The lack of administrative consistency is also reflected in operating practices at a time when pilots are being relied on as the only consistent factor in the operation of foreign-flag vessels while transiting pilotage waters. State pilotage limits access to the pilotage system, resulting in a relatively closed profession. As a result, misgivings have been expressed about the workings and motivations of state pilot associations, particularly by operating companies that pay pilotage fees and by the NTSB.

Under state pilotage systems, measures to confirm maintenance of pilot knowledge and skills are informal; systematic measures are not used to detect and correct degraded capabilities before such weaknesses become factors in marine accidents. Nevertheless, detection and correction of performance problems occurs to some extent, although once a pilot is qualified for unrestricted service, detection is more by chance rather than by design. The disciplinary record once accidents occur is difficult to assess, because data generally have not been published, and because the significance of accidents varies considerably between individual events. But, as far as the committee could determine, the effectiveness of corrective action at the state-level by pilot associations and pilot boards has been uneven.

OTHER FORMS OF PILOTAGE

Docking, Undocking, and Mooring Services

Docking and Mooring Masters

Docking and undocking of vessels and mooring them to offshore buoys call for special maneuvering and shiphandling skills and usually involve working with harbor tugs. A person who boards a vessel for the specific purpose of handling a docking or undocking with the assisting tugs is generally known as a docking master (or docking pilot).

On the West and Gulf coasts, docking and undocking services are provided by marine pilots. In most East Coast ports, dockings and undockings are principally handled by docking masters, generally former tug captains who are affiliated with tug companies. Some docking masters also handle the majority of intraport movements requiring tugboat assistance, primarily in the Port of New

York and New Jersey, and also in the Port of Jacksonville, Florida, and the river ports of Wilmington, North Carolina, and Savannah, Georgia. Mooring to offshore buoys on the Gulf and West coasts are typically performed by shipping company employees serving as mooring masters.

Tug assist work in the Port of New Orleans. Docking and undocking evolutions are directed by river pilots on the lower Mississippi River. Working in close to the propeller is dangerous but necessary, and requires high levels of skill and precision coordination between the pilot and the operator of the assisting tug.
(Wayne Young, *Marine Board*)

In most ports, state-licensed pilots are not required for the docking, undocking, or mooring of foreign trade vessels. Some states also have not required state-licensed pilots for intraport movements. Under the current rules of the New York Board of Pilot Commissioners, for example, a pilot's services end when the vessel has been brought across the bar "to a safe anchorage, or to a position in the immediate vicinity of the berth to which the vessel is bound, unless the master formally requests the pilot to assist with the docking or mooring."

The Coast Guard considers a docking master to be engaged in pilotage under 46 U.S.C. 8502 during docking or undocking or in-port movement of a coastwise vessel, so the docking master must operate under the authority of a federal pilot's license or endorsement (USCG, 1991). Virtually all docking masters hold a federal pilot's endorsement on their operator (or merchant marine) license, and they typically have extensive harbor tug experience. However, most of their work involves ships in foreign trade in ports where neither federal nor state jurisdiction has been exercised over docking vessels or in-port movements in that trade (see Crowley, 1991; Parks, 1982). Thus, docking masters are not acting under their federal license and therefore are not accountable to a pilotage authority when directing and controlling docking evolutions or serving as harbor pilot for in-port movements of foreign trade vessels.

Docking masters acknowledge the gap in official accountability and say they want official sanction for the services they provide, including harbor pilotage. They have indicated to the committee that long-term resolution of this situation is up to the states, although they would accept official Coast Guard recognition of their role and services if the states failed to act.

Training and Practice

Most docking masters, if not all, have formed associations, usually retaining an affiliation with a tug company through some form of employee or management relationship, or a retainer. The associations or tug companies with which they are affiliated set standards for practical training and experience. Modern training methods such as manned-model shiphandling and computer-based ship bridge simulation have not been used; whether such approaches would be of value in training docking masters is not certain. High-technology positioning systems beyond basic radar appear to be used infrequently during docking and undocking; their accuracy and reliability for these evolutions remains to be established for most port settings. Indeed, high-technology docking systems are not even available at U.S. port facilities. Docking master dispatch typically is handled by the tug company.

Accountability

Docking masters usually hold federal pilot licenses, which are required for serving the coastwise trade. However, as noted earlier, docking and undocking operations are not conducted under the authority of these licenses when they involve vessels in foreign trade, because neither the states nor the Coast Guard has exercised jurisdiction. This is a significant gap in official accountability. Whether docking masters providing services to vessels in foreign trade should be held accountable to a licensing authority has been the subject of considerable debate (Crowley, 1991; Journal of Commerce, 1992b,d; USCG, 1990a).

This gap may be compensated for in some cases by the docking master's professional accountability to associations, tug companies, or shipowners. However, these relationships inevitably mix issues of professional competence and safety performance with economic considerations. The complexity of the accountability issue and the link between economic and safety considerations is illustrated by the situation in the Port of New York and New Jersey (Box 3-7).

Docking masters contend that industry influences motivate their vigilance in maintaining competent professional performance, because they are directly observed by:

- state pilots who, depending on state pilotage requirements or pilot association policy, may remain aboard during the docking process;
- vessel masters concerned with possible damage to their vessel;
- port facility operators concerned about potential damage to their structures and impacts on their operations; and
- tug masters, whose vessels and crews could be jeopardized by maneuvering orders given by the docking master.

Docking masters say they quickly hear about any lapses in their performance, particularly from those who may be endangered, the operators and crews of assist tugs. If a threat is severe enough, the tug masters can bring it to the attention of the tug company (with which they and the docking master are affiliated) or the docking master's association. However, the committee could find no data indicating how often this occurs or how effective it might be.

While company and association policies and relationships with docking masters vary, a docking master whose performance jeopardizes a tug company's assets or docking business is a liability. These market forces may have the greatest impact on large tug companies, because small tug companies have limited resources to fall back on if a performance problem is acknowledged. On the other hand, the often-heavy competition between harbor tug companies for business creates at least a potential ethical if not maneuvering problem for docking masters. Possible scenarios include less than optimal tug assistance ordered by an official representing the ship in order to reduce costs, or contracting tug assistance from one towing company when more suitable equipment may be available from a competitor. The latter scenario could prove particularly troublesome for some docking masters because of their direct affiliations with tug companies. No data or testimony were available to establish whether or to what degree business pressures affect docking practices.

Similarly unavailable are statistically valid comparative assessments of the performance of marine pilots performing docking services versus that of docking masters for the same routes and types and sizes of vessels. Such an assessment would be necessary for a determination of the effectiveness of market forces in establishing professional accountability, as compared with oversight by licensing authorities.

Assessment of Docking and Mooring Services for Vessels in Foreign Trade

The committee could not compare the safety performance of docking masters and marine pilots in the provision of docking services to vessels in foreign trade, due to insufficient data and lack of an accepted methodology. Although docking masters virtually all hold federal pilot's licenses, they do not act under these licenses when serving vessels in foreign trade. Nevertheless, they are subject to professional oversight, albeit neither official nor consistent. This gap in official accountability may be compensated to some extent by professional accountability generated through market forces, but the possibility remains that substandard performance or practices may be undetected or uncorrected until an incident or accident occurs. Safety and licensing authorities have not established requirements or programs to offset these possibilities. This lack of official ac

BOX 3-7 HARBOR PILOTAGE AND DOCKING SERVICES PORT OF NEW YORK AND NEW JERSEY

Harbor pilot and docking master services in the Port of New York and New Jersey illustrate the complex nature of pilotage in the United States, the link between economic and safety issues, and the range of issues that need to be considered when improving pilotage systems.

Docking and harbor pilotage services for domestic trade ships are available from federally-licensed pilots from four docking master, one federal pilot association, and two state pilot associations. These services are used as needed by shipping companies to satisfy compulsory federal pilotage requirements. Official accountability is established through federal licensing requirements. All bar pilot services and some harbor pilotage services for in-port moves of foreign trade ships are provided by the United Sandy Hook Pilots of New Jersey and the United Sandy Hook Pilots of New York, and which operate jointly; deputy branch pilots are initially assigned to small ships and are routinely called upon to dock them (Vincent A. Black, Sandy Hook Pilots Association, personal communication, October 22, 1993).

According to data from the Maritime Association of the Port of New York and New Jersey, docking masters provide docking and harbor pilotage services for over 90 percent of in-port, tug-assisted ship movements. They provide similar services for a like number of ships coming from or departing for sea (a state-licensed pilot is required onboard foreign trade ships while transiting to or from the vicinity of the berth or anchorage).

State pilotage jurisdiction has not been exercised by either the states of New York or New Jersey for in-port movements or docking and undocking evolutions of foreign trade vessels, although related legislation is pending in each state. The Coast Guard has initiated federal rulemaking under existing enabling authority to fill the gap in official accountability for docking and harbor pilotage services provided to foreign trade vessels (FR 58 [130]:36,914-36,918). The number of arrivals to the port by ships in foreign trade has declined substantially over the past two decades in response to changing ship cargo capacities and economic conditions, although the number of ship arrivals appears to have leveled off (actual net cargo tonnage has remained relatively constant in recent years), affecting the work available to both state-licensed pilots and docking masters. Safety per countability to a licensing authority is not consistent with the pilotage requirements that are generally applicable to foreign trade vessels.

Pilotage in Federal Canals

The Cape Cod Canal and Chesapeake and Delaware (C&D) Canal are federal navigation projects controlled by the U.S. Army Corps of Engineers. Federal

formance and official accountability factors have been offered as reasons for requiring state-licensed pilots for in-port movements of foreign trade ships (Journal of Commerce, 1992a,b,d; Leis, 1989, 1992; USCG, 1990a), although shiphandling during docking evolutions and control of tugs during harbor pilotage in main port areas has primarily been performed by the docking masters (AWO, 1992b; Booz, Allen and Hamilton, 1991; Cahill, 1985).

Docking master shiphandling and harbor pilotage skills are developed through towing industry service of up to 10 years and apprenticeships. Some docking masters are also maritime academy or college graduates (Richard P. Wieners, McCormick Pilot Association, personal communication, July 29, 1991). The Sandy Hook Pilots' 7-year professional development program for apprentice pilots builds basic maritime expertise, including docking drills with pilot station boats, and is designed to qualify them to provide all pilotage services. The program is accredited by the New York State Board of Regents for Non-Collegiate Sponsored Education for college credit and has been approved by the Coast Guard as satisfying sea service requirements for the first class pilot license. All new apprentices are maritime academy or college graduates. Computer-based shiphandling simulation has recently been instituted for continuing professional development of deputy and full branch pilots (Vincent A. Black, personal communication, October 22, 1993).

Comparisons of safety performance needed to support informed decision-making for pilotage have typically addressed the number of accidents with little attention to actual piloting functions, which are quite different in terms of exposure to risk and the shiphandling skills and experience required. Further, some studies have found generally consistent safety performance by federally-licensed pilots, docking masters, and state-licensed pilots (Booz, Allen and Hamilton, 1991; Leis, 1992; USCG, 1993c). Requiring state-licensed pilots for in-port movements of foreign trade ships is within the domain of state authority. However, depending upon economic effects, such action could result in a shift of in-port movement and possibly some docking business from docking masters to pilots in the existing state pilot associations unless the docking masters were somehow brought under the jurisdiction of the pilotage programs in New York and New Jersey. At the same time, the pilot commissions in each state must ensure that there are sufficient revenues to maintain an appropriate infrastructure for pilotage services, including a sufficient pool of qualified bar pilots and, for this port region, an all-weather, at sea station boat.

pilot's licenses or endorsements are required for commercial vessels in domestic trades on these canals as on other federal waters. For vessels in foreign trade, pilotage requirements vary. The states of Maryland and Delaware require pilotage for the C&D Canal. The state of Massachusetts requires a state-licensed pilot for tankers in the foreign trade that moor at an electrical generating plant located part way through the Cape Cod Canal. Beyond this, there are no state requirements for pilotage in that canal. The Corps of Engineers, which regulates transits of the canal, has an operational policy requiring a licensed pilot (either federal or state) on ships and tugs with tows (33 CFR 207.20); however, the Corps of Engineers does not have authority to establish pilotage as a regulatory requirement (USACE, 1980). Most ships that transit the canal are regular customers, are familiar with local navigation difficulties, and take licensed pilots without question. According to the Army Corps of Engineers, there have been no major casualties in the Cape Cod Canal since 1977. Regardless, Coast Guard-proposed pilotage rules noted earlier are intended to fill this gap in the absence of state action.

Pilotage in the Towing Industry

Barges under tow and their accompanying tugs or towboats are subject to state pilotage rules if they are engaged in foreign trade and transit state waters. Few barges, however, are engaged in such trade—these are principally large integrated tug and barge combinations and very large freight barges. Most barges are in coastwise and inland trade. If they are coastwise seagoing vessels and carry oil or hazardous cargoes, then they are subject to Coast Guard pilotage rules. If they are limited to inland trade, then they are not subject to pilotage requirements. This section focuses on the Coast Guard rules that are applicable to the tug and towing industry; the piloting of inland tug and barge combinations also is addressed, as these vessels share the same channels as oceangoing ships.

The towing industry is quite different from the shipping industry, owing to distinctly different operating characteristics. The inland and coastal towing sectors also differ considerably with regard to tug and barge types and towing configurations. From a piloting standpoint, ship and tug operations are distinguished by the means of direction and control. A ship master or marine pilot, when conning the vessel, issues orders to a helmsman, who responds verbally and executes the commands; the conning officer's engine orders are given to the engine room by the mate or controlled by the bridge-engine room control unit. In contrast, a tug captain has direct tactile control over vessel steering and may have direct control over the propulsion system. A tug operator also has frequent opportunities to gain local knowledge and boat-handling experience.

Some barges are larger than some ships, and barge trains (or flotilla) may be of extended length, for example, up to 1,200 feet for inland tows on portions of the lower Mississippi River. Considerable vessel maneuvering skills are required

River tug and tow in push-tow configuration. The specific skills required to maneuver river tows differ from those required to maneuver ships, because of significant differences in maneuvering characteristics and differing steering equipment employed aboard river towboats. (*American Waterways Operators*) to handle these large tug and barge combinations. Interaction of these units and ships in confined channels can present challenging maneuvering scenarios. Thus, a potential exists for collisions and rammings involving vessels with and without licensed pilots; the consequences can be severe, considering the nature of cargoes transported. For example, a multivessel collision in Tampa Bay on August 10, 1993, involved 546-foot and 442-foot tank barges, each pushed by a tug in the notch, and a 345 foot foreign-flag bulk carrier. The accident featured explosion and fire aboard one of the barges and abandonment of the pushing tug by her crew, pollution from a hole in the other barge, and intentional grounding of the bulk carrier to prevent her sinking. Also involved were federal pilots aboard one of the tug and tow combinations and state-licensed pilots aboard the other two vessels (Barstow, 1993; OSIR, 1993h; Park, 1993).

Pilotage for Coastwise Towing Industry Vessels

Prior to 1980, the Coast Guard did not apply pilotage rules to tank barges in coastwise trade. The case of *Moran Maritime v. U.S.C.G.,* 526 F. Supp. 335, 1981 A.M.C. 2778 (D, D.C.), held that the Coast Guard was correct in its interpretation that pilotage requirements applied to tugs towing tank barges of more than 1,000 gross tons (AWO, 1992b; Parks, 1988). Thereafter, until 1985, licensed federal pilots were required for barges over 1,000 gross tons. In 1985, the Coast Guard adopted a special pilotage rule for coastwise tank barges (carrying oil or other hazardous cargoes) of 10,000 gross tons or less. (Very few tank barges exceed 10,000 tons; for them, the regular Coast Guard pilotage rules apply.) A tank barge of 10,000 gross tons is nevertheless very large; up to 7 million gallons of product can be transported. According to the Coast Guard, the special rule was intended to relieve financial and paperwork burdens on the agency and the towing industry, and the rule was based on an analysis of the cost of barge accidents and the cost of requiring barges to carry licensed pilots (50 FR 121).

For tank barges of 10,000 tons or less, the 1985 Coast Guard rule does not require a licensed pilot. However, under the same rule, a coastwise seagoing self-propelled vessel over 1,600 gross tons, such as a small tanker, would require a licensed pilot. The rule allows the licensed master, mate, or operator of the tug or towboat to "act as" pilot of the tug/barge unit if the requirements specified in the rule are met (46 CFR 15.812). The Coast Guard considers "acting as" pilots to be licensed pilots within the meaning of the federal pilotage laws and thus not exempted from pilotage requirements. This position was upheld in 1986 by a federal district court (*American Pilots v. Gracey*, 631 F. Supp. 827, 1986 A.M.C. 1406 [D, D.C.]; Parks, 1988). However, the "acting as" pilots are subject to licensing criteria that are less stringent than those for mariners holding Federal First Class Pilot's Licenses or endorsements.

To "act as" pilot, the operator first must be licensed at the minimum as an operator of uninspected towing vessels. Requirements for this license are listed in Box 3-8. The operator also must have six months' service on a towing vessel and have completed 12 round trips over the route in question, eight with a barge in tow. The towing industry claims that company-provided professional development programs, normal operating practices, and long-term employment within the industry (usually with a single company) together provide the experience necessary to act as pilot and that safety performance is good (AWO, 1992b; Farrell, 1991; TBS, 1985).

BOX 3-8 REQUIREMENTS FOR LICENSE AS OPERATOR OF UNINSPECTED TOWING VESSELS

- U.S. citizen, 21 years of age
- Annual physical examination
- No convictions of dangerous drug offenses; no history of drug addiction
- Completion of approved first aid and CPR courses
- Written recommendations from recent marine employers and at least one master of a vessel on which the applicant has served
- Written Coast Guard examination
- 36 months of service, six of which must be duty or training in the wheelhouse
- 3 months of required service in the particular geographic locale for which the application is made
- Radar Observer's Certificate (for ocean service only)
- Able Seaman certificate (for ocean service only)
- 12 round trips over the route as observer or under instruction in the wheelhouse, including three trips made in darkness if the route is to be traversed in darkness
- At least one round trip over the route to be traversed within the preceding 60 months

Round trips may be made as an "observer," without hands-on experience or active training. A "round trip" usually means a trip to a single facility on the route, not necessarily a transit of the entire route. With respect to ports, a transit to any dock or berth satisfies the requirement. Skill and knowledge are not tested. Tug masters, mates, and operators may "self-certify" their qualifications and need not furnish evidence thereof to the Coast Guard unless it is requested; Coast Guard officials report that evidence rarely is requested. Thus, although there may be documentation, there is no official, qualitative means for verifying or validating an individual's qualifications.

Coastwise service is marked by frequent port entries and exits. Therefore, the towing industry contends that experienced tug masters, mates, and operators have substantial opportunities to gain familiarity with local waters and to develop specialized skills to pilot tug-barge units (AWO, 1992b; Farrell, 1991; Ramaswamy and Grabowski, 1992). The coastwise nature of these operations does not distinguish the towing industry from much of the rest of coastwise shipping except that the maneuvering of multiple units is more common in the towing industry.

Some tug companies, when they use marine pilots, do not allow them to direct and control movement of the tug/barge combination unless the pilot has towing industry experience and is an expert in handling tugs and barges (AWO, 1992b). To ensure adequate knowledge and skills, some of the larger companies in the towing industry impose requirements of experience and other qualifications on their tug masters, mates, and operators that are significantly higher than are Coast Guard standards for persons "acting as" pilots. Such requirements may not be economically feasible for some towing industry companies that operate only a small number of vessels, because they lack the resources necessary to underwrite in-house professional development programs. (Information developed by the committee concerning practices of smaller companies was insufficient to allow a comparative analysis.) Regardless, there are no accreditation procedures for tug companies' professional development programs.

Pilotage of Inland Towing Vessels

Inland towing industry vessels operate on many of the same waters as coastwise and foreign trade vessels, and routinely interact with these vessels when doing so. The piloting of inland towing vessels has come to public attention principally through allisions with bridges, especially one that resulted in the derailment of an Amtrak train in Alabama with great loss of life (Phillips, 1993; USCG, 1993d). Although an assessment of pilotage requirements for inland towboats exceeds the scope of the present study, the piloting of these vessels and the professional development of vessel operators is described insofar as available information permitted.

At one time, federal pilotage was required for the operation of many inland vessels, including uninspected towing vessels. Pilotage of inland vessels greater than 15 and less than 100 gross tons was mandated by 46 U.S.C. 404. As a result, many operators of towing industry vessels held Federal First Class Pilot's Licenses or endorsements for vast stretches of the nation's inland navigable rivers. (For licensed operators under the age of 21, Second Class Pilot's endorsements were issued.) The pilotage requirement was deleted in 1980 by Public Law 96-378 so as to enable the Coast Guard to establish a crew complement in the certificate of inspection on a vessel-by-vessel basis. This authority appears to have been applied exclusively to passenger vessels. As a result, piloting knowledge and skills for inland towing vessels are developed entirely through company training programs (Appendix F).

Although First or Second Class Pilot's endorsements are no longer required by the Coast Guard, a few inland towing industry companies have in the past required pilot's endorsements to advance to master or give preferential treatment for advancement (T. Allegretti, personal communication, December 16, 1993; W. Creelman, personal communication, November 15, 1993). Bonuses were also sometimes given to employees holding pilotage credentials (W. Creelman, personal communication, November 15, 1993). However, as with the coastwise towing industry, data are not available on the extent of pilotage practices, the beneficial effects on operational safety, and on the differences in the abilities of large and small companies to provide effective professional development programs.

Public Criticism of Pilotage in the Towing Industry

The committee received considerable testimony and correspondence that were critical of pilotage requirements in the towing industry (Ramaswamy and Grabowski, 1992). Critics of pilotage requirements and administration as they apply to the towing industry (Crowley, 1991; NRDC, 1990; Ramaswamy and Grabowski, 1992; Sanborn, 1991; Sankovitch, 1993) argue that:

- requirements for "acting as" a pilot are seriously inadequate, and self-certification of qualifications means that even those standards are not verified or documented;
- the Coast Guard does not supervise compliance with these requirements;
- the inadequacy of present federal standards is underscored by the fact that large towing companies have much higher standards for their own personnel;
- a significant percentage of oil is transported in coastal and inland waters by barges and small tankers, and oil spills resulting from barge accidents are a major source of marine and coastal pollution;
- towing operations present unique shiphandling and seamanship challenges, suggesting the need for standards that are higher than those currently in force; and
- the Coast Guard's accident-cost analysis supporting the 1985 special rule was deficient in that it, among other things, did not take into account important costs, including natural resource damages and the risk of major loss, and assumed that tug owners would engage independent pilots if subjected to pilotage requirements.

Insufficient data were available to prove or disprove statistically the effectiveness of pilotage of coastwise shipping in either the towing or shipping industries. The safety data maintained by the Coast Guard provide very limited insight on safety performance. The Coast Guard has not conducted a comprehensive assessment of safety performance relative to its pilotage program. The shipping and towing industries have produced studies based on Coast Guard data that they claim tend to support the Coast Guard's approach to pilotage for towing vessels (AWO, 1992a,b; Booz, Allen and Hamilton, 1991; Farrell, 1991; TBS, 1985); these studies are discussed in Appendix E. The Coast Guard's analysis of its casualty data for self-propelled vessels yielded similar results (USCG, 1993c).

Pilotage of Military Sealift Command Ships

The U.S. Navy's Military Sealift Command (MSC) provides cargo service to the Department of Defense. MSC-operated or chartered vessels are either not subject to pilotage as public vessels or subject to either federal or state pilotage if operating under enrollment or registry. Navy-owned MSC ships are considered to be public vessels if crewed by MSC civilian employees; these vessels are not subject to either federal or state pilotage. Vessels chartered and operated by MSC under a demise charter and crewed by MSC civilian employees are considered public vessels and are not subject to pilotage. The following MSC-owned or chartered vessels are not considered public vessels and are subject to pilotage; federal or state pilotage depends on their documentation (John J. Hartke, U.S. Coast Guard, personal communication, March 15, 1993):

- Navy-owned MSC ships operated by private ship management companies under contract to MSC;
- vessels chartered by MSC under a demise charter but operated by a contractor; and
- vessels operating under a time charter to MSC.

Pilotage of Inland Passenger Vessels

Because some passenger vessels such as ferries operate solely on inland waters, they are not subject to existing federal pilotage laws, which apply exclusively to the coastwise seagoing vessels. However, the Coast Guard, under authority of 46 U.S.C. 8101, can establish special conditions for manning on a vessel's COI. The Coast Guard generally requires Federal First Class Pilot's Licenses or endorsements for the operation of certain vessels carrying passengers for hire. In this manner, pilotage becomes vessel-specific and is applied selectively in ports, harbors, and inland river systems.

Pilotage for Dredges

Self-propelled seagoing hopper dredges are eligible for exemptions from federal pilotage requirements (non-self-propelled dredges are transported by tugs). Most hopper dredges were originally owned and operated by the U.S. Army Corps of Engineers. As public vessels, they were not subject to federal pilotage requirements. Prior to the passage by Public Law 100-329 in 1988, dredging was not a coastwise trade. About the same time, some of the Corps of Engineers' dredges were privatized. These developments caused the Coast Guard to apply pilotage statutes to self-propelled hopper dredges. The dredging industry persuaded the Congress that the 1988 law was not intended to affect any operational aspect of dredging. Further, they argued, imposing pilotage requirements on these shallow draft maneuverable vessels would result in substantial costs to the government and the increased costs would be passed back to the taxpayer. The Coast Guard did not object to an exemption of these vessels from pilotage requirements as long as the exemption would be discretionary (NADC, undated; USCG, 1990a). Very limited information was identified relative to the navigational safety of self-propelled seagoing hopper dredges, and no systemic safety problems were identified to the committee.

European and British Columbia Pilotage Systems

The committee collected considerable information concerning the pilotage systems in Western Europe and British Columbia (Appendices F and H). This information, which provided a useful counterpoint to U.S. pilotage systems, is summarized below.

Pilotage Systems

In Europe and Canada, pilots are viewed in the traditional sense as master mariners that are independent of the vessel. They provide expert local knowledge and shiphandling expertise that is necessary for safe and efficient port arrivals and departures. Pilots may serve port complexes and their approaches, as in most European ports, or they may serve entire regions, as in British Columbia. A wide variety of pilotage models are used; none has been demonstrated to be more effective than the others. Pilotage models occasionally have been changed, primarily to improve efficiency. Safety and economic efficiency of competing port complexes are dominant themes in the provision of pilotage services, regardless of whether pilots are organized as independent contractors, members of a pilot corporation, or civil servants. Marine pilots in some ports, particularly in the Netherlands, are heavily involved in supporting VTS operations to improve both safety and efficiency.

Pilot Qualifications

Heavy emphasis is placed on the professional competence of pilots in western European and Canadian waters. The qualification program in Rotterdam is perhaps the most rigorous, requiring theoretical, simulator, and practical training and examinations, but all pilotage authorities require considerable experience and apprenticeships. Small commercial craft and some coastal vessels are generally exempt from compulsory pilotage.

Member states of the European Community generally provide pilotage exemption programs for ships of other European Community countries on set runs, such as North Sea Ferries. However, exemptions are controlled tightly. They require licensure of the person receiving the exemption by the appropriate European Community country, and are usually vesseland route-specific, require considerable trip frequency, and usually require that the master or mate be subjected to a rigorous practical and theoretical examination. Exemptions for smaller vessels, however, may be based on vessel size or operator experience. Essentially, masters or mates receiving exemption certificates are placed under the same professional qualification requirements as the pilots, although only for their particular route and ship (or sister ship). The exemption certificate is not a broad-based pilotage endorsement; it does not entitle the holder to pilot other types or sizes of vessels or to provide service on other routes. Exemption programs are intended to ensure a baseline level of pilotage proficiency for all vessels, whether subject to compulsory pilotage or piloted by masters or mates holding exemption certificates.

Pilot Training Using Shiphandling Simulation

The committee found growing interest among marine pilots in the use of both computer-based ship bridge and manned-model shiphandling simulations. Such simulations are generally considered a valuable training aid, but they are not the primary means of training pilots. The primary means continues to be apprenticeships, which provide exposure to a wide variety of vessels under a wide variety of operating conditions. This experience allows candidates to mature professionally through progressive accumulation of local knowledge and professional expertise. Simulations, where employed, build on and help refine an individual's capabilities; if combined with theoretical classroom work, they serve as a practical on technical matters. For both manned-model shiphandling and computer-based ship bridge simulations, pilots or pilot candidates all come to the training with considerable nautical experience. No organization was found to be using simulation as a means to reduce the time necessary to qualify as pilot. Marine simulation is not used in licensing in the United States except in approved courses leading to the radar observer's certificate required for some Coast Guard-issued licenses. OPA 90 brought additional attention to shiphandling simulation by requiring the Coast Guard to examine its application for training of tanker officers.

Although many pilots have found manned-model shiphandling and computer-based ship bridge simulations valuable, questions remain about the efficacy of simulation for broader application in training and licensing. Areas of concern include the validation of simulators and simulations for training, the necessary level of fidelity for visual scenes and vessel behavior, the adequacy of training objectives and curriculum, the qualification of simulation instructors, and the transfer of training to actual operations (Guest, 1992a,b; Herberger et al., 1991; Marine Institute and IMD, 1993; NRC, 1992a; Webster and Young, 1993).

IMPROVING PILOTAGE PRACTICES AND ADMINISTRATION

Longstanding federal and state interests in pilotage have become greater as the potential consequences of marine accidents to public and environmental safety—and public awareness of them—have grown. Although the multijurisdictional administration of pilotage has been in effect for more than a century, it is unwieldy and has a number of obvious shortcomings. These include:

- non-availability of a written code of professional ethics;
- gaps in formal accountability to licensing authorities for docking and mooring evolutions and for some marine pilot operations;
- general absence of training requirements or programs for decision-making and application of shiphandling skills under the stress of emergency situations;
- lack of recertification requirements to establish that pilots maintain requisite knowledge and skills at acceptable levels;
- discipline of federally and state-licensed pilots only after an accident, rather than through advance constructive measures designed to detect degraded skills or other performance problems before they become part of the error chain in accidents;
- placement of ancillary responsibilities, such as determining and reporting operational deficiencies, on marine pilots;
- relief from rigorous port-specific pilotage requirements for the domestic coastwise trade;
- lack of formal pilot training and quality control programs to ensure professional competency;
- great diversity in pilotage requirements, system administration, and pilot development programs, all of which result in pilotage systems of varying quality;
- lack of completeness in pilotage models employed as compared with the committee's model; and
- joint jurisdiction over pilotage routes but not the vessels using them.

Some of these shortcomings have been under review for years by the Congress, the Coast Guard, the NTSB, state pilotage authorities, and other bodies, but with limited effect. Meanwhile, most coastal states have reviewed and are revising (or are considering revising) their pilotage laws; these include Alaska, California, Connecticut, Florida, Hawaii, New Jersey, New York, Oregon, and Washington. Also, questions have been raised as to whether pilotage regulation in the towing industry adequately addresses navigation safety needs.

Regardless of who administers pilotage, basic issues still need to be resolved concerning what standards should be applied, how qualification should be conducted, who should be licensed, what the pilot's role should be, and how pilotage should be administered.

Alternatives for Improving Pilotage Systems

The central features of a complete pilotage model are presented in Chapter 3 and Appendix F. Using this model as the frame of reference, the following actions could be taken to improve pilotage systems.

Establish National Guidelines or Standards

The great variations among existing pilotage models leave much to chance. All pilotage could benefit greatly from well-conceived national guidelines or standards that could be used by pilots and governing authorities alike in improving their pilotage models and performance. The establishment of national guidelines is essential to build public confidence in pilotage requirements. Guidelines or standards would benefit the following areas:

- *Pilotage*. General principles would be chosen for designation of pilotage waters and the vessels subject to pilotage (including their movements in port). These principles would take into account the degree of hazard as affected by: vessel types; substandard vessels, equipment, or crews; nature of cargoes; and waterway, weather, and other conditions. For example, in some cases, the use of two pilots or pilots with special qualifications might be required. If more than one pilot is used, one should be designated as the senior pilot. The senior pilot would be responsible for explaining the division of responsibilities to the master, and in particular, which pilot will take the conn.
- *Selection of pilot candidates*. Guidelines would help ensure that the best and most qualified applicants are chosen for training. Pilot candidates would be required to have recent and substantial prior experience at sea or in the towing industry, in service as masters, mates, pilots, or licensed operators, unless adequate training were provided to substitute for such experience.
- *Training of pilot candidates*. Training would include extensive service under the direct supervision of active pilots, in all waters, operations, and vessels to be covered by the license.
- *Licensing*. Guidelines would cover all aspects of a license, including duration. Licenses might be issued for short terms; issued initially for vessels of limited size, type, and risk (excluding, for example, tug/barge units or vessels carrying oil or other hazardous cargoes), with limits removed gradually as the pilot gained experience; renewable only upon showing of recent and suitable work as a pilot, and compliance with retraining requirements.

- *Continuing and special-purpose professional development*.
- *Pilotage boards*. Guidelines would specify their composition, authority, staff, proceedings, and accountability. Such boards, for example, could be established under state law as state or local agencies; members could be appointed by and responsible to the government. Membership could include pilots, other subject matter and marine industry experts, and public representatives. Boards would need to meet regularly and frequently and would need adequate staff and other resources to administer pilotage and conduct investigations. Their proceedings could be recorded and open, and they could publish annual reports of their activities.
- *Pilotage certificates or other credentials.* These certificates would authorize suitably qualified masters or mates to perform pilotage services aboard their vessels; they would be issued by pilotage boards for the ports and waterways under their jurisdiction. Certificates of exemption would be issued after examinations only to persons serving as masters or mates of designated vessels, on specified routes or waters, who have suitable and recent experience on those vessels and routes. Certificates also could be granted to experienced docking masters for pilotage in tug-assisted transits of port areas adjacent to docks.

Establish Code of Professional Ethics

Some professional associations have established codes of professional ethics which members are asked or required to observe in order to remain a member in good standing. Although not universally adopted, such codes are available in the medical, legal, accounting, engineering, and environmental professions. Generally in pilotage, there is an unwritten code of professional ethics that has been handed down as a part of the tradition of pilotage. This tradition could be developed into a written code of professional ethics by professional organizations or trade associations. Such codes could appropriately address the issue of financial interest in support services beyond provision of pilot services and other ethical issues.

Establish Universal Entry-level Qualifications

A certain baseline of prior service, knowledge, and practical skills is needed in order to serve effectively as a pilot. The Federal First Class Pilot's License is effectively a prerequisite for most marine pilot development programs, and it thus is a de facto national entry-level standard. This standard could be made official and could be enhanced in terms of knowledge requirements, training, and validation of skills.

Pilot candidates must meet minimum service criteria to qualify to take the examination for a federal pilot's license or endorsement. The examination process provides for a minimum level of theoretical nautical knowledge as well as local knowledge. However, the federal licensing program by itself does not ensure competence, because there is no quality control over pilot training through professional evaluation. Written recommendations from previous employers do provide some testimony to a candidate's competence. Conspicuously absent is a demonstration of piloting proficiency; such proficiency could be demonstrated through a required field test. Alternatively, marine simulation, although not fully perfected for all piloting tasks, could potentially be used to demonstrate or evaluate proficiency for some tasks following the example of the federal radar observer's requirement.

If federal and state-level pilotage were consolidated into a single pilotage system for each port or port region (an option discussed later in this chapter), then the existing federal pilotage requirements could be reformed into a pilotage certificate program, which would establish that an individual has demonstrated knowledge and skills at national entry-level standards for the profession. The certificate would convey no official sanction to engage in the profession. Such a certificate could be required as a prerequisite for all who wish to serve as a pilot, regardless of who administers pilotage.

Require Emergency Shiphandling Training

Most, if not all, federal and state pilot associations, docking master groups, and pilot companies follow very similar professional development concepts. Fundamental elements include substantial prior marine service or equivalent apprenticeships and extensive familiarization with pilotage routes, vessel behavior, and shiphandling. None of these groups, however, have requirements for developing emergency shiphandling or decision-making skills prior to licensing, and few have such requirements in place for pilot advancement. Marine pilots and docking masters generally possess the shiphandling skills necessary for emergency maneuvering due to loss of propulsion or steering systems and to react to extreme maneuvering situations. But, individual capabilities for decision-making under stress have usually been developed through actual service rather than through specialized advance preparation, such as marine simulation training. Thus, while a pilot or docking master may have the necessary shiphandling skills, they may have to learn how to think through emergency scenarios, assess emergency maneuvers, and make time-critical decisions under the stress of an actual crisis. If the ability to process emergency data has not been established beforehand, reaction time can be slowed and decisiveness impaired, increasing the probability that the pilot or docking master's actions will not achieve desired results.

Marine simulation training, subject to the concerns noted previously, nevertheless provides a means to prepare pilots for emergency shiphandling decision-making and actions. Simulations of this type also could be used to screen pilot apprentices and licensed pilots for ability or continued ability to perform under stress.

Require Continuing Professional Development

There are few formal requirements for continuing professional development once a pilot is fully qualified, although some state and federal pilot associations voluntarily promote such development, and some states are making it a requirement. There is also no formal network for ensuring that information about changes involving regulations, pilotage authority policies, or other matters affecting the piloting profession is systematically disseminated to all pilots and docking masters. The piloting profession could help itself by establishing and widely distributing newsletters for active pilots and docking masters. Requirements could be established by either associations or governing authorities for continuing development or refresher training in theory and practical application of skills. This training could include marine simulations and classroom study.

In addition to the primary objectives of increasing and refreshing knowledge and enhancing proficiency, continuing professional development requirements can serve as one means of motivating pilots to meet the expectations for highly professional services from licensing authorities, the marine community, and the public.

Require Pilot Recertification

There are few requirements for periodic recertification of knowledge, skills, and performance once a pilot is fully qualified. Various methods could be employed to gauge a pilot's continued suitability for service or unrestricted status. These methods include written examinations, spot checks by pilot examiners, check rides, shiphandling simulations (within the limits of capabilities), and review of performance history. Because of the nature of their business relationships and liability concerns, state and federal marine pilot associations have not adopted these measures for evaluating their colleagues. Pilot governing authorities have not adopted such measures either. However, their oversight responsibilities make licensing authorities suitable candidates for conducting such assessments. Qualified pilots could be appointed as pilot examiners under the authority of the licensing body, thereby providing a means for professionals with superior credentials to assess the performance of other members of their associations. Through a recertification program, bad habits could be detected and corrected, needs for refresher training pinpointed, and performance problems requiring further professional assessment identified. A complete recertification program would also include provisions for a physical examination to insure that there are no physical conditions that would impair performance.

Verification of Professional Competence

Professional development, regardless of the licensing authority, could be improved through either voluntary accreditation or formal approval processes to satisfy national standards. Instructors also could be certified to prescribed standards, including attendance at an instructors' course as in aviation, thereby improving consistency of training. Yet, while there are good reasons for verifying pilot professional competence, it is not clear whether the infrastructure and professional expertise available are sufficient to support a professional validation program, either using vessels as the media or through simulation.

If a formal approval process were chosen, the approving authority could be the Coast Guard. Only the Coast Guard operates a national infrastructure for maritime operations and licensing and has a longstanding credible record of service in these areas. On the other hand, there is concern over whether the Coast Guard has sufficient resources and resident technical expertise to set or validate pilot qualifications. Moreover, an expanded Coast Guard role could be viewed as a further regulatory intrusion into company operating practices. Actual or perceived gaps in the Coast Guard's technical expertise for verifying competency could be filled by advisory bodies or special commissions, which could be staffed by the Coast Guard but with qualified practitioners from the marine community (or government sources) serving as examiners. A variant would be to accredit piloting profession training programs so that completion of training satisfied national proficiency requirements, following the example of Coast Guard-approved marine education and training curricula for the purpose of satisfying marine licensing requirements.

Alternatives to Coast Guard administration include appointment of another federal agency or of a federal commission for this purpose. If voluntary program accreditation or instructor certification were required, a jointly sponsored organization involving government representatives and marine pilot organizations or an existing accreditation organization could be used. Each approach would require a modest commitment of resources. Potentially, measures for demonstrating or validating proficiency as an element of professional development could be built into national standards for program accreditation or approval. Well-qualified federally and state-licensed pilots could be appointed as assessors to evaluate pilot candidates, providing the local expertise that would be necessary to determine fitness. Such an approach would draw on existing resources and thus would not require an expansion of the federal infrastructure to administer a full-scale program to validate professional competence. This approach also would provide a means to establish the credibility of accredited professional development programs throughout the marine community and with the public.

Establish Vessel Type and Size Criteria for Federal Pilotage

Federal rules allow a master or mate with a pilotage license or endorsement for any gross tons to pilot any vessel without regard to its type and with little regard to its size. (An exception is when the Coast Guard OCMI issuing the license or endorsement has limited it, such as to tug and barge combinations, because of an individual's experience. No data are available that indicate the frequency of this practice.) By contrast, shipping and towing companies generally provide for progressive advancement of their employees. Some state pilotage systems require progressive advancement. But like the federal system, some state pilotage systems do not categorize pilot qualifications or provide for progressive advancement, although this generally happens in practice. In recognition of the fact that vessels handle differently depending on their hull form, mass, and propulsion and steering systems, pilotage requirements could be established according to vessel type (insofar as this reflects different handling characteristics, e.g., tug and barge, ship, ferry) and size to establish a reasonable progression allowing licensed pilots to advance their skills. Categories of ship (e.g., tanker and bulk carrier, containership, liner) may be appropriate for restricted shallow water conditions, however, as all ships are affected by the same hydrodynamic forces, size is the dominant factor in ship behavior (MacElrevey, 1988).

If this approach were adopted for federal pilotage, masters and mates of ships and tugs could continue to perform pilotage, if properly credentialed, but the criteria for obtaining pilotage endorsements would become more stringent. Only individuals with substantial service aboard a specific vessel (or class of vessels) within a size range could qualify for pilotage on a given route. Of course, operational and economic implications of this alternative would need to be assessed thoroughly before implementation. Mooring masters permanently employed by an operating company but not a member of a vessel crew also could qualify for similar service. Under this scheme, the occasional practice of temporarily employing a licensed federal pilot (who may lack proper experience) simply to satisfy a regulatory requirement (and thus circumvent its intent) would be diminished or eliminated. Shipping and towing industry companies might be inconvenienced. However, the traditional principle that a master is best qualified to handle the master's own vessel would be preserved to the degree that masters were able to obtain federal pilotage endorsements.

If federal pilotage were to be enhanced through vessel- and route-specific criteria, the federal system for coastwise vessels would be much closer in form and function to rigorous pilotage systems found in some European countries. Other countries require an examination and field test prior to issuing certificates of exemption, and the certificates may not be applicable for some cargoes or weather conditions. If such a change were successfully implemented and if it also were adopted for U.S.-flag vessels in foreign trade, it could help provide a basis for abandoning dual pilotage for each pilotage route in favor of a single pilotage system for each port region. Pilotage based on trade could be replaced with pilotage based on vessel flag. Of course, an administrative body for the single pilotage system in each pilotage district would have to be chosen. Local or state authorities could handle this responsibility if their program were accredited or approved and operated in accordance with acceptable national standards.

Relieve Federal Pilots of Non-Pilotage Duties

Under the federal pilotage rules applicable to coastwise vessels, the master, mate, or operator is authorized to perform pilotage if the individual holds the appropriate credential or qualifies as an "acting as" pilot for towing industry vessels under 10,000 gross tons and ships under 1,600 gross tons. A vessel officer or operator on watch who serves as its pilot, with responsibility for navigation, also remains responsible for watch officer duties, unless assisted by a second officer or operator. Such assistance allows a deck officer piloting the vessel to concentrate solely on navigation without distraction. It is generally more available on ships than on coastwise towing vessels. Distractions from navigation responsibilities are common where one person routinely performs all wheelhouse, navigation, and piloting functions, as is common aboard coastwise towing vessels.

When marine pilots are directing and controlling a ship's maneuvers in the presence of a full bridge team (master, mate, and helmsman), the mate performs watch officer duties and, with the master, provides navigation support to the pilot. This traditional arrangement can be stressed, however, in some cases where the helmsman position has been eliminated (for example, following installation of advanced navigation systems), and manual steering is necessary. In such situations, either the mate or the master must take the helm, a new task that may distract from their principal duties (if the bridge is not configured to fully support this task). Or, in a traditional bridge configuration, the master must call another crewmember to the bridge to man the helm. In the latter case, the crewmember performing the helmsman function may not have the necessary skills, because they are not developed or practiced aboard the ship. This situation may call for an additional bridge team member to ensure sufficient capabilities to handle all necessary tasks in pilotage waters without distracting from navigation responsibilities. Judging from past operating experience of high-technology passenger ferries in the Baltic Sea, fully integrated bridge systems (validated in terms of accuracy and reliability for use on a pilotage route) support manual steering by the mate or master qualified to pilot on that route. It is not clear how well this capability would transfer to situations where the master or mate is unfamiliar with the route and a pilot is directing and controlling the movement of the vessel. However, in the case of a mate performing manual steering, fully integrated bridge systems would be expected to produce significantly better results than does a traditional bridge configuration.

Although not currently required to do so, some shipowners or masters may place an additional watch officer on the bridge when transiting difficult waters. As required by OPA 90, the Coast Guard has issued a final rule that mandates a second officer on watch on tankers of 1,600 or more gross tons operating on U.S. navigable waters. This rule applies to both coastwise and foreign trade vessels, and it "will allow one officer to concentrate on the safe movement of the tanker through the waterway while the other officer assists as necessary with navigation and performs other important watch functions" (58 FR 88:27629). The rule could be expanded to cover tank barges that are subject to a federal pilotage requirement, either for waters that pose difficult operating conditions or where there is a special need, such as transits through congested harbors, confined waters with populated shorelines, or environmentally sensitive areas. Analysis of safety, economic, and environmental impacts would be necessary before considering expansion of the rule.

Closing Institutional Gaps

Institutional gaps exist with respect to pilotage requirements for certain waters and to official accountability. In some case, institutional gaps exist because there is no apparent operational need for pilotage although there is jurisdiction. This is the case for foreign trade vessels where the pilot boarding area is located inside of three nautical miles. The same general situation exists for federal pilotage because pilotage requirements are linked by regulations to the boundary line rather than the territorial sea. It is expected that the master is capable of safely navigating to the pilot boarding area, although some marine accidents have occurred due to faulty approaches (Associated Press, 1994; Cahill, 1983, 1985; NTSB, 1991b). Except where pilot boarding areas are already located offshore due to operational needs, the committee found no compelling operational reason that would justify *universal* relocation of pilot boarding areas to the three mile line, much less to the 12 mile international boundary. However, for environmentally sensitive areas, pilotage authorities might consider special pilotage regulations insofar as jurisdiction extends to these areas. It appears that most approach problems could be effectively addressed through marine traffic regulation (Chapter 5), particularly since vessel traffic service operations could be designed to cover areas seaward of pilotage jurisdictions.

The Coast Guard has advised the committee that it is considering rulemaking that would authorize the master of a coastwise vessel to act as pilot between the three mile territorial sea and the boundary line so that there is no gap in official accountability for pilotage. As a practical matter, the master is already accountable to U.S. licensing authorities for navigation. However, if the Coast Guard were to apply such a rule to foreign trade vessels, then the master of a foreign-flag ship could potentially be held accountable to the Coast Guard under U.S. licensing regulations.

Substantial gaps exist in official accountability for services provided by docking and mooring masters, some bar and harbor pilots in California, and some harbor pilots in other states. The absence of an official pilotage requirement and accountability to licensing authorities does not necessarily mean that piloting is not effective or not achieving acceptable safety levels, but it does mean that a satisfactory level of professional training and competence is not ensured by the licensing authorities. Cognizant licensing and marine safety authorities have not established a statistically valid measure of safety performance that is acceptable to the public and could serve as a benchmark for pilotage determinations. Performance monitoring by the Coast Guard of pilotage for coastwise vessels, ships, or tugs with tows, is at best limited. Still, the public has demonstrated a strong lack of tolerance for marine accidents resulting in major pollution or substantial loss of life.

Where official accountability does not exist, it is because state jurisdiction has not been fully exercised over vessels in foreign trade and the Coast Guard has not exercised its secondary jurisdiction to fill the void. Because pilotage for these vessels is a state responsibility, state governments or local pilotage boards or commissions could quickly close gaps in jurisdiction, and thus improve accountability. They could issue state licenses to docking and mooring masters with or without consolidating them into existing state pilot organizations, or they could require existing state-licensed pilots to direct and control all vessel movements in pilotage waters, as the Coast Guard does for coastwise trade. If the states do not fill these gaps, the Coast Guard can propose rules under existing enabling legislation to require federally-licensed pilots (Hall, 1992; USCG, 1990a). As discussed earlier, the Coast Guard has begun rulemaking to establish official accountability in certain waters of California, Hawaii, Massachusetts, New Jersey, and New York. The state of Massachusetts has already responded to this Coast Guard initiative by requiring state pilotage for foreign trade vessels operating in the Cape Cod Canal. Coast Guard action to close remaining gaps in official accountability in California and East Coast ports is contemplated.[1]

[1] As this report was being completed, there was an interesting development in foreign trade pilotage. In March 1994, an American shipping and towing company began bi-weekly foreign trade service between the Port of Memphis on the Mississippi River and Latin America using a 298-foot containership (Sansbury, 1993). Foreign trade commerce has not been of sufficient volume in the past to have motivated the establishment of state pilotage requirements for Mississippi River waters in the states of Arkansas, Mississippi, and Tennessee. The American company that initiated foreign trade service and charter the foreign-flag ship that is providing service on the route, has as a matter of company policy after consultation with the Coast Guard and state pilots in Louisiana (who are providing pilot services to Natchez, Mississippi), required that piloting be under the direction of a federally-licensed pilot on river waters north of the Louisiana-Mississippi state border. Pilotage services are being provided by a combination of state-licensed pilots with federal pilotage endorsements and federally-licensed pilots (Pat Johnson, Dixie Carriers, personal communication, April 11, 1994).

Jurisdictional Gaps in Ship Pilotage, Docking, and Mooring

While it is desirable to close existing gaps for vessels in foreign trade, this must not be done in such a way that the very intent is circumvented. The objective of closing the jurisdictional gap is to ensure the use of local experts organized to provide pilotage services in a specific pilotage district and who are regulated by and accountable to that pilotage district's licensing authorities.

Simply requiring a federally-licensed pilot for foreign trade vessels could create a situation in which anyone with a federal pilot's license or endorsement for the route could offer independent service or could be employed as a member of a foreign-flag vessel's crew to provide pilotage service. To guard against these possibilities, special provisions must be made to ensure the use of locally based marine pilots, docking masters, and mooring masters operating under the oversight of pilotage district licensing authorities. One option would be to permit services only by associations approved by the Coast Guard or accredited by an accountable third party. Alternatively, the Coast Guard could establish a pilotage system for each port where state authorities do not close existing jurisdictional and accountability gaps. Enabling legislation and changes in existing Coast Guard concepts for pilotage administration may be required to implement some aspects of this option.

Docking, Undocking, and Vessel Transport Services

The gaps in official accountability and the exercise of pilotage jurisdiction for docking and mooring are current topics of interest to government, marine industry, and the public, and these issues have become very controversial. There are three ways in which official accountability could be established over docking masters. They are (1) to establish a federal requirement for federal pilot's licenses (discussed earlier), (2) to create separate state licensing procedures for docking masters, or (3) to integrate docking and mooring masters into state pilotage systems by issuing them state licenses and making them members of an existing pilot association. Any of the options would effectively close the gaps; none stands out as substantially better than the others except that options 2 and 3 better fit the local expert approach favored by the committee. In implementing any of these options, issues of concern include preserving the integrity of services now provided; local economic considerations; and, depending on the option chosen, organizational and cultural factors.

Another approach now used in Delaware (Box 3-9) is to require a state-licensed pilot to be aboard for all foreign trade vessel movements in a pilotage jurisdiction (some state pilot associations require their members to remain aboard in the absence of an official requirement to do so). Although the state-licensed pilot is accountable for services the pilot provides, including docking the vessel, this approach does not establish accountability for docking masters if they are used.

BOX 3-9 PILOTAGE ACCOUNTABILITY BAY AND RIVER DELAWARE

The pilot commissions for Delaware and Pennsylvania recently required that assigned state-licensed pilots remain on board inbound ships until the first line is ashore. The state pilot is not required to dock the vessel but is available to do so at no additional charge if requested by the master. The state-licensed pilots say that they serve as safety observers and as additional expert resources working in partnership with both the master and docking master (if holding the conn). The state-licensed pilot also may intervene to relieve a docking master, under the authority of the state pilot's license, if circumstances necessitate such extreme action in the interests of safety; this rarely occurs. The intervention criterion is the expert opinion of the state-licensed pilot. It is unclear whether an intervention would occur once an *in extremis* situation has developed; a relief of the conn at a critical point in an evolution, especially aboard foreign-flag ships where language may be a problem, could confuse an already difficult situation. The liability of a state-licensed pilot who intervenes and becomes involved in a marine accident is uncertain.

In 1990, following a series of groundings and other accidents involving tank vessels and oil spills in the Port of New York and New Jersey, the Coast Guard convened a board of inquiry into these accidents. The board's report (known as the Henn report, for its chairman) concluded that docking masters should be subject to either federal or state licensing requirements (USCG, 1990a). Federal action in response to the Henn report to close gaps in state pilotage are in progress, as previously discussed. Related state action has been attempted in New York and New Jersey (Journal of Commerce, 1992b) but has not been brought to closure. Some other states, such as Pennsylvania and Delaware, require the state pilot to be stationed on the bridge throughout the entire voyage, including the docking evolution, even though a docking master usually is employed. In these cases, the state-licensed pilot is not accountable for a docking master's actions but is available to perform docking and undocking evolutions if requested to do so by the master. Some state pilot associations, as a matter of policy, have established the same requirement.

The Coast Guard has expressed concern that requiring federal pilotage for intraport moves and docking, without establishing a local pilotage system, could lead to a proliferation of individuals attempting to provide such services. An "open" pilotage requirement also could result in employment of U.S. nationals holding federal licenses or endorsements aboard vessels engaged in foreign trade, thereby undermining state pilotage programs. The Coast Guard has consistently indicated that it does not wish to establish and administer local pilotage systems, other than the existing federal system for the Great Lakes. Extending state requirements for pilotage to and from the pier would close the licensing gap. In any case, the institutional gaps in accountability could be closed through legislative or regulatory action by either the states or the Coast Guard without disrupting services.

The second option mentioned earlier is for state or local commissions to create a separate license for docking masters affiliated with recognized docking master or pilot associations. If adopted, this approach would enfranchise existing associations while also perpetuating current docking master affiliations with tug companies. The docking master's ability to engage in the profession would be controlled by both official governance and market forces.

The third option is for state or local commissions to consolidate docking master services into existing state pilot systems. This approach would sever the relationship between tugboat companies and docking masters and likely would be opposed. Quality assurance responsibilities for docking master skills would be lifted from the tug companies, thus reducing their ability to protect their investment by influencing who will direct and control the movements of their tugs at vulnerable times. Tug companies with affiliated docking masters oppose measures that might impair their relationships with them. At the same time, state pilot associations and commissioners oppose consolidation because of concerns over the ability to economically support an expanded number of state-licensed pilots. Yet, both docking masters and state-licensed pilots continue to operate in East Coast ports, although reductions in the number of calls in some ports such as New York have reduced the number of pilots that can be supported. The piloting profession by nature does not respond quickly to changes in shipping trends and practices.

Consolidation of docking masters, harbor pilots, and bar pilots was accomplished in the San Francisco Bay area. The transition has not been entirely smooth; cross training was required, and debate continues even today after ten years of transition. This debate focuses on economics rather than safety performance (Thomas, 1993; Wastler, 1992a,c, 1993c,d,e). Nevertheless, this approach potentially could be employed to bring all piloting services under a single system in each port.

State pilots also oppose making docking and undocking services subject to compulsory pilotage that requires pilot direction and control. One reason is their concern, as independent contractors, over potential liability for damage to a vessel or facility during docking evolutions. Shipping companies likewise oppose measures that would prohibit a vessel's master or mate from docking the master's or mate's own vessel. Marine pilots and company management reason that the master or senior mate on certain vessels with unique operating character istics, who has extensive familiarity with both the vessel's behavior and the route, is typically the most qualified to conduct docking and undocking maneuvers.

Redefining the Pilot's Role

The traditional role of the marine pilot is expanding under strain. First, marine pilots must maintain effective master–pilot working relationships under increasingly difficult operating conditions. Second, marine pilots are increasingly being expected, if not actually required, by some governing authorities to act as quasi-public officials in detecting and reporting substandard ships and deficient onboard operating conditions.

Master–Pilot Working Relationship

The traditional master–pilot relationship provides both shared decision-making responsibility and a means of direct safety oversight. It is not useful or even possible to define the pilot's duties or the master–pilot relationship more specifically by law or regulation because of the infinite variety of circumstances that might arise. These issues could be left to the courts and administrative bodies on a case-by-case basis; numerous decisions on related questions already have been handed down over the years. The related provisions of state laws—making the pilot either an adviser to the master or a servant of the shipowner—probably are intended to deal with liability for damages rather than the pilot's role in navigation. Questions of liability involve matters of public policy that are beyond the scope of this report.

Marine Pilot Responsibilities Relative to Substandard Ships

It is likely that some officials will increasingly expect marine pilots to detect and alert them to substandard conditions aboard ships. To formalize this process, criteria could be developed for use by pilots in detecting substandard ships and crews and in taking action to ensure that federal and state interests in public and environmental safety were satisfied. Pilots would fill an alerting rather than an enforcing role, except to the extent that the pilot can decline to provide services if the vessel is patently unsafe or perhaps move it to a safe anchorage to await correction of deficiencies.

The responsibility of the pilot to direct the navigation of the vessel already involves the use of reasonable care—by conferring with the master and perhaps other means—to be sure that the vessel may be navigated safely to its destination. If the vessel is found to be unseaworthy, then the pilot can decline to provide services by notifying the proper authorities. If a problem develops after the pilot boards, then the transit can be halted if necessary (for example, by anchoring the vessel). The pilot also has the option of notifying appropriate authorities regarding deficiencies observed that threaten vessel, port, environmental, or public safety. While this authority is customary and in some cases codified, it is not widely exercised. Informal reports (often without attribution) are more common.

Burdening the pilot with ancillary duties could create rather than alleviate safety problems. Additional responsibilities that do not pertain to marine pilots' inherent or prescribed operational responsibilities could interfere with their ability to direct and control vessel maneuvering, thus compromising their primary role. However, pilots are in a position to detect some operating problems or deficiencies from their normal duty station on the bridge. There needs to be a balance between the pilot's primary purpose and responsibility aboard a ship and the provision of support to marine safety authorities. In the committee's judgment, attempting to use the pilot as a law enforcement official is counterproductive to piloting duties. Rather than burden the pilot with enforcing national or state interests, it would be more beneficial to ensure adequate vessel-operating conditions by other means and to improve vessel master and bridge team capabilities to oversee or support the pilot. A combination of international cooperation and port-state initiatives would be required to motivate vessel owners and management and operating companies to provide quality crews and adequate bridge teams.

If marine pilots are indeed expected to act as quasi-government officials providing a line of defense against substandard ships and crews, then it would be desirable to find ways to strengthen this responsibility without jeopardizing the master/pilot/bridge team working relationships that are essential to onboard cooperation and safe navigation. Methods could be developed for alerting cognizant authorities of actual or potential problems that would affect safe navigation. As in the case of the master–pilot relationship, however, legal definitions may best be left to case-by-case determination by the courts and administrative bodies.

Improving Pilotage in the Towing Industry

The Coast Guard has not systematically assessed the effectiveness of its 1985 rule regarding tug and barge pilotage. Further, correspondence and testimony to the committee reflected substantial concern that safety could be endangered by inadequate standards for coastwise towing vessels and by the lack of official pilotage credentials and standards for operators of inland towboats and barge trains.

There are insufficient data to determine statistically whether the piloting of tugs and barges is any more or less safe than the piloting of ships. Generally, operators of both coastal and inland tug-and-barge combinations—at least those employed by large and responsible companies—are required by their employers to have more experience on local routes and in vessel handling than the mini mum standards for federal pilotage, particularly for the transport of petroleum cargoes (AWO, 1992b; Farrell, 1991; Sanborn, 1991). The existence of these company requirements shows that these companies consider federal criteria insufficient for their needs (Sanborn, 1991). This state of affairs implies a need to strengthen federal pilotage requirements for coastwise towing vessels.

While market forces may be sufficient to motivate attention to safety performance in some cases, they do not ensure universal concern. As with pilotage generally, official quality control to ensure professional development and safety performance is absent, and informal control is not consistently applied. Further, the safety of tug and barge navigation is of particular concern —as has been noted by the Coast Guard, NTSB, and others—because of the hazardous cargoes involved and the potential for marine pollution resulting from collisions, groundings, and other accidents.

The Coast Guard's authorization for vessel operators to "act as pilots" acknowledges that there is a need for pilotage but does not provide assurance that the requirements are met. A tug operator is given status as a form of licensed pilot without determination or certification of professional competency to serve in this capacity.

Although assessing pilotage in the inland towing industry is beyond the scope of the present study, the navigation and piloting of inland towboats and barge trains is of interest, because these vessels share pilotage waters with oceangoing ships and often transport oil or hazardous cargoes. The nature of pilotage in the inland towing industry certainly needs to be understood by the pilots of oceangoing ships that may encounter inland vessel traffic.

The Coast Guard can take disciplinary action against the federal license of an individual operating an inland towing vessel. However, there is no pilotage requirement (or license). The absence of a pilotage requirement means there is no systematic official oversight to ensure the professional competence of vessel operators to pilot tug and barge combinations in waters shared with oceangoing ships. Some companies in the inland towing industry employ rigorous on-the-job pilot and master development programs, but the full extent of this practice is unknown. There are no data or analyses that demonstrate a safety-based need to expand pilotage in the inland towing industry. To cover the possibility of any deficiencies, however, the pilotage licensing process could be extended to include inland services. Or perhaps an equivalent effect could be achieved through accreditation of towing industry professional development programs for personnel piloting vessels and the establishment of associated standards by a credible organization having official accountability.[2]

[2] In 1988, after a long study and public meetings and comments, the Coast Guard proposed to adopt a rule (still pending) under which tug masters and operators would be eligible for federal pilot licenses for tug and barge combinations if they met the following requirements; (1) 5 years of service on tug and barge combinations of at

Consolidating Pilotage into a Single Program for Each Port and Waterway System

Pilotage in the United States is a patchwork of laws, regulations, customary practices, overlapping jurisdictions, and gaps in coverage. This approach has developed in a piecemeal manner. The number of coastwise transits by U.S.-flag ships, upon which the federal pilotage program is predicated, has greatly diminished. Theoretically, pilotage could be provided under a single program in each pilotage region without adversely affecting safety by building the revised system around the strong points of the existing state and federal pilotage systems. Existing requirements for a federal pilot's license could be reformed as a certificate program to establish uniform entry-level criteria for all pilots. The fact that U.S. ship masters and senior mates serving permanently aboard the same U.S.-flag vessel or sister vessels on regular routes can under these select conditions potentially achieve high levels of piloting expertise for their vessels could be acknowledged through a pilotage credential program that verifies competency. Such an option would also satisfy the economic concerns of operating companies with respect to the cost of independent pilots. Credentials could be issued as vessel-and route-specific endorsements to the federal pilot's license or a master or mate's license, or could be a separate authorization issued by the pilotage licensing authority for jurisdiction over the pilotage route.

Because of the importance of pilotage, any changes to the current approach would need to be carefully planned and executed to ensure that safety performance is not compromised and that economic issues are addressed equitably. Nevertheless, implementation of improved standards appears to be possible.

Consolidating Ship Pilotage Under a Single Authority

All ships could be subject to the same pilotage authority regardless of flag or trade. This authority could be federal or state. Federal interests could be served by combining some of the previously discussed approaches into a national program. The first step would be to establish national standards and means for their implementation and then to bring all elements of the consolidated system up to these standards. Pilotage of all ships then could be administered under the state pilotage concept, subject to establishment and operation of pilotage systems meeting basic national guidelines for administration and standards for professional competence and accountability. State authorities would continue to

least 5,000 gross tons, with 2 years on combinations of at least 10,000 tons, while actually acting as master, mate, or operator (not merely holding a license as such), and (2) completion of the same number of round trips over the route applied for as are required for other applicants for federal pilotage endorsements, with two thirds of the trips on combinations of at least 1,600 tons. This proposal offers an example of improved standards that might be appropriate for "licensed" persons who "serve as" pilots under the Coast Guard's 1985 rule.

have the authority to shape pilotage rules to meet specific local needs. A system organized this way would avoid the present duplications of staff and costs. Transitional arrangements would be needed for marine pilots licensed under the present federal system, to transfer them into the respective pilotage systems for the ports served.

Implementing National Standards and a Port-Level Pilotage System

The objective of national standards of pilotage, administered by a port-level system, would be to ensure the development of qualified pilots for all vessels subject to pilotage requirements, whether in coastwise or foreign trade. These standards would also form the foundation upon which port-level pilotage systems could be formed. Administration would be decentralized, conducted by regional or local authorities responsible for accommodating port-level concerns. The port-level authorities would ensure adequate professional development of pilots, issue licenses, and oversee pilotage administration and pilot performance in their ports and waterways under rules that meet or exceed national standards. These pilotage requirements could be supplemented as necessary by additional rules to reflect changing port-level needs for achieving safe navigation and protection of coastal populations and environments, within the limits of state jurisdiction. The Coast Guard still would exercise its COTP responsibilities as they pertained to navigation, piloting, and port safety. Correction of deficiencies that might arise in a port-level pilotage system would be best addressed at that level or close to it; however, if other remedies fail, the Congress would continue to have legislative authority to enact any laws needed.

A major implementation issue for the port-level pilotage-system concept is the manner in which national standards of the profession would be developed and implemented. As described earlier, the general approach to professional regulation in the United States involves reliance upon professional organizations within major disciplines to develop or propose standards, which then may be incorporated into laws, regulations, or licensing requirements. Pilots as well as state and federal pilotage authorities would need to be intimately involved in the formation of any national standards to ensure their effectiveness and their acceptance by the professionals they affect. Similarly, a broad range of interested parties who rely on pilotage also need to be satisfied with the quality of the standards; such parties have safety, economic, and environmental protection concerns associated with the movement of waterborne commerce in ports and waterways. Finally, as with other professions where there is public trust involved, public interests need to be represented in the setting of standards of pilotage.

Several approaches could be employed in the setting and oversight of professional standards. Sometimes professional standards are developed by professional bodies and either applied voluntarily within a profession or incorporated into official rules and regulations. At the state-level, standards for pilot develop ment have been incorporated to some degree into some pilotage laws and regulations, but performance standards have not been established. Although much of the expertise required to develop standards for pilotage rests with the pilots, a more representative process would provide a basis for standards reflecting broader community interests.

A federal agency could be designated or a commission with a permanent staff could be established to develop and issue national standards applicable to all pilotage jurisdictions, federal and state. Initial questions are (1) whether the setting of pilotage standards and oversight of their implementation would be best performed by a federal agency or by an independent commission, and (2) whether, in the case of a commission, it should be advisory or have regulatory status. Only two federal agencies appear to be reasonable candidates for such a role if assigned to an agency, the Maritime Administration (MARAD) and the Coast Guard.

MARAD has a longstanding mission in marine education and training, operates a federal maritime academy supporting the merchant marine, and supports state-level maritime academies. It does not have pilotage administration responsibilities and thus has not been directly involved in the national pilotage debate. The agency has a sufficient infrastructure and, with access to the necessary expertise, could establish national standards. However, MARAD would need substantial added resources and regulatory authority to develop the nationwide administrative infrastructure necessary to oversee implementation of national standards at the field level.

The Coast Guard has considerable responsibilities for and experience with administration of coastwise and Great Lakes pilotage. The Coast Guard could promulgate regulations that incorporated professional standards developed, for example, by an agency task force, professional association, advisory committee, or independent commission. The agency has a nationwide, regional, and port-level infrastructure that could be adapted for implementing national standards at the port level. However, representatives from the various segments of the marine community expressed concern to the committee that the Coast Guard may have (1) insufficient expertise to develop credible national pilotage standards, (2) lack of resolve to set rigorous pilotage qualification requirements, (3) insufficient professional expertise and resources that would be necessary to oversee pilot performance at the port level, and (4) insufficient working relationships in many port areas to obtain professional advice from the marine community. The Coast Guard's ability to access professional expertise from external sources at the port level varies because of factors such as the presence of proprietary and special interests within the various segments of the marine community, varying capabilities of Coast Guard port-level officials to work with the commercial and public sectors, and little apparent federal support for additional advisory committees at the port level. Further, these factors and the history of pilotage, especially the lack of rigorous federal pilotage qualification requirements, suggests to the com mittee that direct Coast Guard oversight of a port-level pilotage system would not be accepted as credible by state and local pilotage authorities or state-licensed pilots.

Use of DOT-chartered advisory committees is a longstanding method for providing the Coast Guard with advice on safety, operations, waterways management, and professional development. At the national level, such advisory bodies include the Towing Safety Advisory Committee, Navigation Safety Advisory Committee, Commercial Fishing Industry Vessel Advisory Committee, and the recently authorized Merchant Marine Personnel Advisory Committee (MERPAC) (USCG, 1993a). All are chartered under the authority of the Federal Advisory Committee Act (5 U.S.C. Appendix I) to advise the Secretary of Transportation, via the Commandant of the Coast Guard, for the purpose of shaping policy for the marine industry. MERPAC is specifically charged to address matters relating to the training, qualification, licensing, certification, and fitness of seamen (crewman and officers aboard ship) serving in the U.S. Merchant Marine (USCG, 1993a). The committee is not specifically charged to address pilotage issues. Similar DOT-chartered committees operate at several field locations, such as New York, New Orleans, and Houston, to advise the Coast Guard on safety matters of local interest. These organizations are generally not designed to conduct in-depth assessments, although such activities may be feasible for some issues. The Coast Guard can to some degree influence the selection of committee members and topics. All meetings must be publicly announced in the Federal Register, and all meetings are open to public participation. The advice of advisory committees is nonbinding.

Another option is establishment of a commission through which nationally accepted and applicable standards could be developed. An independent national commission on pilotage, navigation, and waterway safety, with multidisciplinary membership with appropriate professional and technical expertise and capable of effectively representing pilot, federal, state, marine industry, and public interests, could be formed to develop standards for pilotage as well as other port and waterways safety matters. Technical and administrative support could be provided. Such a commission could be responsible for:

- developing national standards for pilotage and marine traffic regulation;
- developing and administering procedures and processes for accreditation of pilotage and marine traffic regulation systems in accordance with nationally accepted and applicable standards;
- defining, promoting, and assisting in the implementation of a consolidated port-level system of pilotage; and
- providing expert advice to the Coast Guard and other pilotage authorities on marine pilotage and marine traffic regulation matters.

A national commission has been proposed before (Ashe, 1984), but the concept envisioned here is much broader in application and includes multidisciplinary membership. Pilotage systems could be accredited by the commission (or perhaps organizations approved by the commission) to the national standards, but operated by local pilotage authorities using the existing pilotage infrastructure. What is envisioned is an accreditation program similar in concept to those used to accredit college and university programs that are designed to prepare individuals for professional careers. Although the national commission would not have operational responsibility, it could encourage and improve accountability by periodically reviewing the performance of local pilotage systems as an element of the accreditation renewal process. It is envisioned that such a process would be accomplished in consultation and coordination with cognizant pilotage authorities and marine pilot associations, users of pilotage services, the Coast Guard, and other appropriate parties. Consultations also could be conducted with port-level advisory committees. As this overall approach is innovative, it would be advisable to periodically review the performance of the national commission so that its success could be gauged and any needed mid-course corrections could be made.

A corrective action mechanism would be needed for cases when a port-level pilotage system did not initially achieve accreditation or subsequently did not fully maintain the national standards. Backup provisions could include, for example, probationary status until corrective actions are completed and full accreditation restored (the committee's preferred option). In the case of a commission without regulatory status, correction of deficiencies would rely on professional and public pressure that could develop in response to the loss of accreditation. In the case of a commission with regulatory status, additional options to motivate corrective action could be established. Probationary status to permit corrective action would again be preferred to more stringent options. In an extreme scenario where less intrusive measure proved ineffective, a pilotage system could be temporarily administered by a professionally credible administrator until the pilotage system were again accredited to national standards. Such an administrator would need to be acceptable to all affected parties, insofar as practical.

The latter approach to pilotage administration outlined in this section mimics federal laws related to safety and environmental protection that set basic standards and authorize states to establish and administer more stringent rules reflecting local needs. (Such laws include, for example, the intrastate pipeline provisions of the Natural Gas and Hazardous Liquids Pipeline Safety Acts and provisions of the Clean Water Act.)

In order for the commission concept to work, considerable implementation analysis beyond the scope of this report will be necessary. In particular, goals and objectives, commission membership, accountability, leadership, administrative location, official status, subject matter expertise, and staff support will be important to success. Careful attention in each of these areas and effective, impartial performance by the commission will also be needed to establish concept and commission credibility with the federal and state governments, marine pi lots, the marine industry, and the public. In order to serve national interests in marine safety, commission membership needs to be carefully composed to assure balance and fair treatment as well as sufficiency of subject matter expertise. A relative small commission, about 5 to 7 members, would seem desirable to facilitate decision-making. The commission's members would nevertheless need to be capable of effectively addressing the professional, technical, policy, and economic interests of the federal and state governments, marine pilots, the marine community (including shipping and towing industry companies, and port authorities), merchant mariners, and the public insofar as these pertain to the commission's mission. Further, the individuals selected to serve would need to be capable of impartial and credible service. In developing nationally accepted standards, a considerable task by itself, the commission could appropriately involve representatives of the pilotage infrastructure and the marine industry.

4

Risk, the Operating Environment, and Safety

SUMMARY

Risk, inherent in every human enterprise, is generally managed by individual or corporate judgments about perceived risks. Although this approach is generally adequate for most routine circumstances, it is inadequate for complex situations. Risk in the complex marine operating environment has increased significantly, because substantial increases in the costs of marine casualties that result in pollution have not been accompanied by a corresponding decrease in the probability of accidents. The probability of accidents might be reduced through improvements to organizational structure and processes, professional development, operating practices, and technology. Whether the combined effects of improvements in these areas could fully offset the increase in economic risk is uncertain.

Mariners are inherently familiar with risk, not in probabilistic terms, but in practical threats to safety that must be avoided or accommodated in operations. Mariners must deal with threats continuously, although they do not always do so effectively. The marine operating environment is very complex and not well understood, even by those who operate in it. There can be substantial differences in threats and exposure even within the same port and waterways complex. There are no practical means for mariners to fully assess all the factors that could affect the safety of vessel movements other than their professional judgments. Their responses to threats reflect their accumulated experience and professional competence as well as the risk management programs of their employers.

Underlying causes of marine accidents have not been addressed methodically or effectively by most shipping companies, marine safety authorities, or other interested parties. Furthermore, the available marine safety data are not adequate to support this objective. No public agency in the United States is systematically monitoring to detect problem ships, inadequate operating and management practices, and substandard crews. Some proprietary monitoring is conducted, but these data are usually not available. When accidents occur, pilotage is frequently an early target for blame. The overall result is that risk management in the marine operating environment depends to a great extent on perceptions of risk and personal judgment. Thus, symptoms of problems rather than underlying causes are often treated. A more informed basis for problem solving could be developed by careful assessment of safety performance, including identification and assessment of underlying causal factors in marine accidents and preventative measures that might be applied.

INTRODUCTION

Risk is inherent in essentially every human enterprise. Managing risk is, therefore, part of all decision-making, whether personal or business related. Although modern probabilistic approaches to risk management are available and proven in other transportation sectors, these methods are poorly understood and not widely applied in marine transportation. Major shipping accidents with oil spills of enormous proportions—*Argo Merchant* on the Grand Banks; *Amoco Cadiz* off Brittany; *Exxon Valdez* in Prince William Sound; and in January 1993, the *Braer* in the Shetland Islands—challenge the capabilities of the maritime industry, flag-state and port-state governments, and international maritime organizations to manage risk more effectively. The first section of this chapter explains the framework for addressing risk in this report. Probabilistic risk concepts and risk management practices based on these concepts are introduced. Established techniques for quantitative risk management in other areas provide a point of comparison for analyzing the traditional methods of risk management in marine transportation. Risk management practices in marine transportation are described. The first section concludes with an overview of the consequences of risk.

The second section characterizes the marine operating environment and the factors that complicate risk management in the marine navigation and piloting stem. The complexity of risk management is not widely appreciated, even within the marine community. The third section examines safety performance. Trend analysis practices in marine transportation are characterized, and causal factors in marine accidents are discussed. The role of pilotage in reducing the probability of marine accidents also is examined. The analysis concludes by offering ways to improve risk management in the marine navigation and piloting system through systematic application of quantitative risk assessment and safety analysis.

RISK

Decision Analysis and Risk

Decision Analysis

Decision analysis may be defined broadly as any activity that involves analysis for purposes of making a decision, or more narrowly as a specific approach to analyzing decision situations. The components of modern quantitative decision analysis include decision trees (and more recently, influence diagrams), subjective or statistical probability, and measures of utility (incorporating risk, multiple attributes, and a time value of consequences). Underlying this quantitative approach is the assumption of maximization of expected utility (Howard, 1988, 1992; Howard and Matheson, 1983; Raiffa, 1968; Simon, 1956).

> The importance each component (decision trees/influence diagrams, probability, or utility) plays in any one particular decision analysis varies greatly; in simple applications, a simple weighted sum of a few attributes done in a few minutes may constitute one decision analysis while another may involve complex combinations of computer models capturing the dynamics of uncertain processes developed through many person years of effort. (Bodily, 1992)

Risk Analysis

Risk analysis is an approach to risk control (North and Yosie, 1987) that permits assessment and management of risks to an individual or an organization due to hazards, deleterious effects, and damage to property. Risk analysis techniques have been used for many years to manage potential hazards in transportation, occupational safety, manufacturing, and financial markets. These hazards may include accidents or injuries, failures, or monetary losses (Covello, 1987).

Risk analysis has been described as comprising three primary components: risk assessment, risk management, and risk communication (Figure 4-1); (Balson et al., 1992; Covello, 1987; NRC, 1989). *Risk assessment* is the qualitative or quantitative evaluation of the environmental, health, operational, or economic risks that may result from some process, activity, or event:

> To assess human health risks, for example, one would combine information about a group's exposure to risky substances with information about the effects of those substances on the human body to derive an overall characterization of the risks a group faces (North and Yosie, 1987). Similarly, to assess environmental impacts, one would use the exposure of an ecological group combined with response information. Operational risks may be assessed by using the fre

quency of an accident or failure and a measure of the magnitude of the hazardous operation. Economic risks may be assessed using estimates of the direct and indirect costs of an incident and the frequency of the incidents. (Balson et al., 1992)

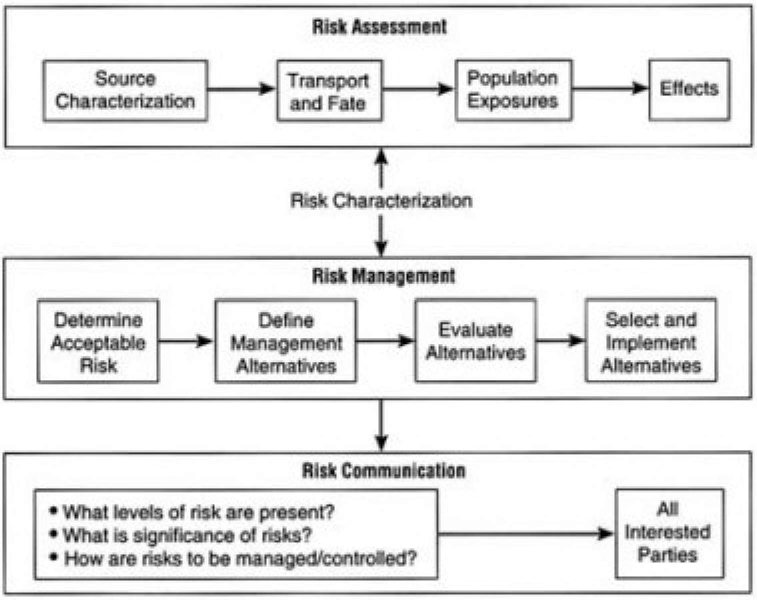


FIGURE 4-1 Main components of quantitative risk analysis (from Balson et al., 1992).

Risk management is the process of determining whether an identified risk is acceptable, and what action (if any) should be taken to mitigate or control that risk. In this sense, risk management is a specific application of decision analysis. *Risk communication* includes all purposeful exchanges of information about health, environmental, or economic risks between interested parties. Through the risk communication process, interested parties share information about the probabilities of risks; the significance of such risks, and the decisions, actions, or policies those parties can use to manage or control such risks (Chorssen and Covello, 1989; Glickman and Gough, 1990; Graham et al., 1988; NRC, 1989; Wilson, 1991). This three-pronged approach to risk and decision analysis has been successfully applied by utilities to manage environmental risk (Balson et al., 1992), by banking operations to manage investment risks (Engemann and Miller, 1992), by large diversified manufacturing enterprises such as General Motors Corporation to manage business risks (Krumm and Rolle, 1992; Kusnic and Owen, 1992), and by military planners to manage risks inherent in requirements and systems acquisition processes (Buede and Bresnick, 1992; Watson and Buede, 1987).

Relationship Between Probabilistic Risk and Perceived Risk

Probabilistic risk is classically defined as the algebraic product of the probability of an adverse event occurring during a defined period and the cost (economic, environmental, or social welfare) that would be incurred if the event takes place. This definition assumes that reasonable values can be assigned to the probability and cost of an occurrence. In many cases, values can be assigned with reasonable certainty, although, until recently, this was seldom done. Most business risk decisions have been and still are based on perceived risk, understood here as the likelihood of adverse consequences derived from nonquantitative interpretation of risk factors as well as from considerations that are often nonquantifiable. Such considerations include experience-based human reactions to unfamiliar circumstances and uncertainty. The formal process of determining the full range of possible adverse occurrences and the values to be assigned to their probabilities and expected costs can be quite involved and expensive. Still, quantitative risk studies have become more common, particularly where they may be used in gaining acceptance or permits for major construction projects.

The probabilities based on accident data are epistemic, that is, they represent a state of knowledge relative to a reference class. The reference class is the set of past occurrences reflected in the knowledge base from which the statistics derive. Therefore, the probabilistic risk is an estimate of actual risk, just as is perceived risk. The difference is that probabilistic risk is quantitative, based on an objectively constructed reference class, and testable against continuing experience.

For reference classes where the rate of past occurrences has been too low to construct a statistically relevant and significant knowledge base, methods have been developed that provide reasonably accurate estimates of accident probability. These methods use structured approaches to model the operations involved and, through the use of tools such as hazards and operability studies, failure modes and effects analyses, fault trees, and decision trees, provide quantitative estimates of the probability of accidents. Values from statistically significant data bases for similar operations are assigned to elements of the fault or decision trees, where available. Expert judgment is used to assign values to those elements that are unique to the studied operations. These methods have been qualified by testing them, with very good results, on models of operations where accident rates are well documented by statistically significant data.

The results of probabilistic risk assessments are useful for examining the effects of introducing new technologies and operational changes. These methods have gained wide acceptance in recent years in the nuclear, aerospace, and pro cess-control industries. These techniques potentially could be used to assess marine operations where historical data is unlikely to yield a statistically significant and relevant knowledge base.

Although subjective, estimates of perceived risk can be fairly accurate if the risk decision is about familiar things or circumstances, but familiarity is often not enough. The fear that many people have of flying is a good example. Most of these people feel very safe riding to the airport in a car or taxi but become anxious and concerned upon boarding the aircraft. More than sufficient data exist to prove there is far greater probabilistic risk during the short automobile trip than during flight. Many aircraft passengers are familiar with these statistics, but the personal sense of danger is stronger aboard the aircraft than when using ground transportation. This example illustrates a disparity between probabilistic risk and perceived risk based on a subjective sense of the likelihood of bad consequences, not the relative value (cost) of the consequences. In a subjective assessment, the probability of bad consequences (that is, the perceived risk) is heightened by unfamiliar surroundings, lack of control, and the severity of consequences should a mishap occur. It is lessened by familiarity with the surroundings, ability to influence the outcome, and the possibility of a range of outcomes including those with minimal potential harm.

As noted earlier, risk decisions based on quantitative models are rare in day-to-day personal or professional lives. Instead, individuals and organizations react to perceptions of risk that, for obvious threats and exposure, are reasonably accurate. This accuracy level tends to reinforce an informal approach to risk assessment. But all too frequently, perceived risk and probabilistic risk are significantly different, and the latter goes unrecognized or inadequately accommodated.

Businesses, like the individuals who operate them, do not always recognize the actual cost of risk. In businesses or operations where the probability of an accident is thought to be low, a structured method is seldom employed for assigning the cost of the risk. Efforts are usually made to keep the probability of an accident at acceptable levels. But, for those very rare occurrences whose costs can only be observed at very long intervals, the perceived risk may be distorted by failure to recognize a significant change in cost. This appears to have been the case in the marine industry during the 1980s.

Following a number of very large oil spills during the 1970s, significant changes were made in the equipment and operating practices of tanker fleets, reducing risk. The number of major oil spills decreased during the 1980s. However, following the pollution from the grounding of the *Exxon Valdez* in 1989 and subsequent major oil spills, three factors—the clean-up and compensation costs incurred by those who spill oil, the Oil Pollution Act of 1990 (OPA 90), and similar state-level pollution legislation—acted together to increase the costs to vessel owners (AWO, 1992a; Freudmann, 1991; OSIR, 1993a,b,c,k; Plume, 1991; Porter, 1991). These changes apply to all merchant vessels involved in oil pollution, not just tankers. OPA 90 also provided for preventative measures involving marine traffic regulation and pilotage to reduce the likelihood of accidents in Prince William Sound. Although operational costs attributable to these measures would increase, risk would be reduced to some extent—a major objective of OPA 90.

The degree to which the probability of accidents would need to be reduced to offset increased risk and the capability of marine transportation companies, especially smaller ones, to reduce accident probabilities are not certain. Probabilistic risk assessments have been performed by some U.S. operating companies, principally by large oil carriers, and might enable analysis of this issue, but these studies are usually proprietary and none was available to the committee.

Marine safety could benefit from increased use of quantitative and qualitative risk analysis in developing risk reduction strategies. This approach is a proven methodology that could form a solid basis for identifying, developing, and evaluating the risk reduction options (Cooke, 1991; Harrald et al., 1992).

RISK IN MARINE TRANSPORTATION

Considerations in Reducing the Probability of Accidents

The increased cost of accidents causing pollution provides a strong incentive to improve safety performance. Increased economic risks often motivate businesses to raise insurance coverage, change operating procedures, add or enhance training of operating and maintenance personnel, update technologies to reduce the probability of a loss, or implement a combination of these options. For example, some shipping and towing companies have invested in improved vessel design, construction, navigation equipment, training, and operating practices. In this regard, the quality of tankers chartered for service to U.S. ports appears to have improved (Arthur McKenzie, Tanker Advisory Center, personal communication, January 15, 1993). Another option—raising insurance coverage—may be a satisfactory response to economic risk, but it is neither a means to reduce the occurrence of accidents nor necessarily an incentive to do so.

Improvements in organizational structure, professional development, operating practices, and technology are the principal methods for reducing the probability of accidents. Major advances to achieve such a reduction may require fundamental changes in navigation and piloting practices, administration and technologies, operational procedures employed aboard vessels, marine traffic regulation (including the setting of limits on vessels or operations in certain areas), and training to use new or updated technologies and techniques. Long-term action may be required to effect some changes, particularly those that require the introduction of new technology, changes in organizational culture or structure, or establishment of support infrastructures.

Traditional Risk Management by Mariners

Mariners are pragmatic with respect to their operating environment and operational risks. They think in terms of threats to vessel safety from physical dangers (such as shoals, rocks, obstructions), other vessel traffic, and environmental conditions. Mariners, their vessels, and cargoes are the immediate recipients of the physical consequences of accidents, regardless of the economic costs, so operational risk is emphasized over economic risk in terms of perceived physical threats and abilities to avoid or counter these threats. To protect themselves, mariners must constantly identify, assess, and respond to actual or potential threats and conduct operations to reduce exposure, insofar as is practical. Their performance reflects the planning and risk reduction measures of their operating companies and the adequacy of their own professional development. Their estimates and procedures are based on experience and may or may not be effective as measures of probability and cost.

Mariners have two basic tools to manage risk: the practice of good seamanship and the effective use of informed judgment derived from accumulated experience and expertise. The general rules of good seamanship are based on a long history of experience developed through trial and error and reasoned response to maritime operating conditions. For example, methods of voyage preparation, including identification of physical threats to vessel safety (from charts and navigation publications) and passage planning to reduce exposure to them, are well established (MacElrevey, 1988; Maloney, 1985; Meurn, 1990). Practical application of these methods varies greatly in form and precision (Cahill, 1983, 1985). Sometimes chances are taken based on professional judgment and a vague sense of the probability of success based on experience. Statistics and methods for formal analysis to determine the probability for success are not available at sea, nor do mariners have the means to develop such measures. But ample evidence exists demonstrating that sometimes informal decisions are in error (Cahill, 1983, 1985; NTSB, 1980, 1986, 1988a,b,c, 1989a, 1991a,b, 1992, 1993; USCG, 1993b,d).

Shippers, port authorities, marine and public safety authorities, and environmental protection agencies also must be concerned with risk insofar as there are threats to human life, the environment, and property. Economic costs must be considered. Too often, the full costs only become apparent after an accident has occurred. Except for companies with much to lose and a sufficient base to fund scientific analysis, there is little evidence that more than cursory attempts are made to systematically assess risk and to manage it in ways that could improve the safety of operations. Thus, the well-intended efforts of many operating companies to improve training, operational procedures, and navigation technology may or may not be directed toward underlying causes of shortcomings or failure in human performance.

Containership outbound crossing the Columbia River bar in common Pacific Northwest weather and sea conditions. (*Columbia River Bar Pilots*)

Assessing Risk in Marine Transportation

Although there are two primary approaches to assessing risk and human error, there is no widely applied methodology for assessing risk or accepted approach for assessing safety performance in marine transportation. Likewise, there is no accepted method for normalizing data to accommodate vast differences among port, waterway, and river systems so that comparative safety performance can be assessed. Furthermore, there is no systematic performance monitoring program to aid in a holistic examination of the risk variables identified in Chapter 1 that affect development and implementation of safety improvement measures. Major safety studies are conducted infrequently, providing a limited basis for determining trends that affect safety. Safety trends are generally derived from analysis of casualty data, but the data are weak with regard to human causes of marine accidents (Fujii et al., 1984; Gates, 1989; Glansdorp, 1987, 1988; Johnson and Katcharian, 1991; Maio et al., 1991; NAS, 1973; NRC, 1983, 1990a, 1991b, 1993; Ponce, 1990; USCG, 1973; Yamaguchi, 1991; Young, 1992). The performance of the marine navigation and piloting system is not routinely monitored through systematic analysis of safety data, nor are existing data adequate for this purpose. Analyses using historical casualty records are not timely enough for near-term adjustment of safety programs. Even if analysis were timely, marine casualty data do not provide a complete basis for considering new or revised safety strategies, policies, and programs.

Existing casualty data are not a complete reflection of the overall nature of safety problems in any port area (Maio et al., 1991; Young, 1992). Systemwide problems may or may not be apparent from single marine accidents. Further, there is no proven way to screen out local causal factors from those of a systemic nature. Comprehensive cause-and-effect analyses are possible but difficult to perform within the scope of available safety and performance data. For example, marine casualty data for specific ports and waterways are often too limited to establish statistical validity for important causal factors. The use of data covering several decades does not fully solve this problem; additional error can be introduced because of changes in shipping practices and technologies during the period. The use of global casualty data provides a sufficient sample but screens out locally significant safety considerations that are important in planning local improvements.

Examinations of casualty records, accident investigations (where detailed reports are available for all casualties), and anecdotal information have proven useful in determining relationships between tasks and error. However, inspection of each case record is required, an intensive effort that is usually beyond the resources available for such research. A few reliable reports and assessments are available (NAS, 1976; NRC, 1983, 1990a; Paramore et al., 1979). Most assessments have been limited to a few performance factors and focus on vessel-specific casualty data rather than human causal factors. Yet, human error is the predominant cause of collisions, rammings, and groundings (Cahill, 1983, 1985; Gates, 1989; NAS, 1976; NRC, 1983, 1990a; NTSB, 1980, 1986, 1988a,b,c, 1989a, 1991a,b, 1992, 1993).

Approaches to risk and safety assessment are receiving renewed attention. For example, Det norske Veritas (DNV), the Norwegian classification society, believes that 95 percent of human errors associated with marine accidents are caused by lack of knowledge, skill, instruction, or motivation. Thus, DNV does not see human error as the real cause of accidents, but the symptom of failure in the management system (Mackenbach, 1992), including the waterways management system and management aboard each vessel (Cahill, 1983, 1985). Further, causal analyses of human error and risk analyses, and quantitative as well as qualitative approaches to assessing risk, are also receiving increased attention. These causal and qualitative approaches focus on identifying causal factors in accidents and risk analyses, as well as latent or potential errors, in an effort to anticipate difficulties in a system, or "to break the error chain" (Grabowski and Roberts, 1993; Harrald et al., 1994; Reason, 1990).

The *Exxon Valdez* grounding and subsequent tanker groundings with oil spillage off Newport, Rhode Island; in New York and New Jersey's Kill Van Kull; and in the Houston Ship Channel were watershed events in renewing attention to the system in which operations occur (Davidson, 1990; NTSB, 1990, 1991a,b; Roberts and Moore, 1993; USCG, 1990a; U.S. Congress, 1991). The Coast Guard, in executing congressionally mandated examination of the need for improved marine traffic control, included risk and exposure variables in the resulting *Port Needs Study* (Maio et al., 1991). The agency is also continuing to develop an exposure data base to provide the resources needed to support a broader examination of risk and safety performance (Abkowitz et al., 1985; Hantzes and Ponce, 1991). Despite these advances, the prevailing approach to safety analysis remains narrowly focused. One subsystem, marine pilotage, is the locus of considerable attention. When vessels ground or collide, close examination of pilot actions are sure to follow.

Consequences of Risk

Risk becomes a matter of direct public concern when major accidents occur. Accidents can pose severe threats not only to the vessels, crews, and cargoes but also to the public, environment, property, and local and regional economies. Short- and long-term consequences have been demonstrated by the stranding and loss of the *Amoco Cadiz* and resulting environmental damage to the Brittany coast (Cahill, 1985), the pollution caused by the *Exxon Valdez* grounding (Alaska Oil Spill Commission, 1990; Davidson, 1990; National Response Team, 1989; NTSB, 1990), and a host of other marine accidents. While the aftermath of accidents has led to public outcry, little public attention has been paid to preventative measures. The movement of hazardous or dangerous cargoes is not reviewed until a major marine accident occurs, especially when accompanied by a major oil spill. Notable exceptions include the movement of dangerous cargoes in bulk (such as liquefied natural gas) and bulk movement of crude oil and petroleum products in Alaska's Prince William Sound and in Washington State's Puget Sound and the San Juan Islands. But some coastal states are becoming more active in addressing local and regional interests in marine safety. For example, both Washington and California have created state offices responsible for addressing marine safety. In Washington, activities of this office include monitoring federal marine safety activities insofar as they pertain to state interests.

The safety measures that have been implemented so far typically address the proximate causes of accidents, not the underlying or systemic factors that contribute to the causal chain of events. Substantial tradeoffs have been made between risk, economics, and safety (Wenk, 1986). The *Port Needs Study* provides some insight on potential consequences of accidents by developing cost esti mates in terms of life, property, and the environment. However, as a practical matter, risk in vessel operations is determined on a case-by-case basis, typically during the course of operations, although passage planning is performed aboard some oceangoing ships prior to entering port or on pilot boarding.

THE OPERATING ENVIRONMENT FROM A RISK ASSESSMENT PERSPECTIVE

A Tale of Six Rivers

> Down here we have 6 rivers—a daytime river and a nighttime river, a foggy river and a clear river, a high water river and a low water river—and we have to pilot on each of them differently.
> *(Mark Delesdernier, Jr., January 17, 1991)*

The characteristics of the nation's ports, waterways, and navigable river systems supporting ship navigation differ from each other significantly, just as the Mississippi River is transformed continually by daily, seasonal, and episodic variations. The lower Mississippi as described by pilot Mark Delesdernier of the Crescent River Port Pilots is only one of the more dramatic examples of pilotage waters in the United States (Box 4-1). In assessing risk, even the six-river characterization of the lower Mississippi River does not reflect the full complexity of the operating environment, which must be understood and accommodated by vessel operators in order to operate safely.

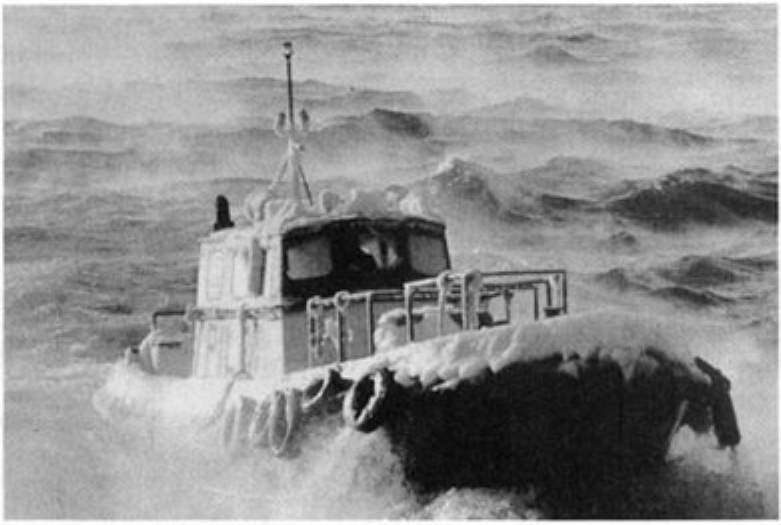
If understanding the complexity of local operating environments is important for the pilot, it is just as important for assessing universal and area-specific alternatives for improving safety and economic efficiency. For example, Automatic Radar Plotting Aid (ARPA) technology, while effective for collision avoidance in open water situations, has not been demonstrated as effective for close-quarters meeting situations in narrow channels (Chapter 6; Zabrocky, 1992). ARPA also has not yet been proven effective for navigation requiring constant maneuvering, as is required in sections of the lower Mississippi between Pilot Town and Baton Rouge, in Kill Van Kull and Arthur Kill (New York), in the Calcasieu and Houston Ship Channels, and in similar waterway configurations (Box 4-2). Thus, ARPA is not an effective safety measure in all situations.

The significant differences among port operating environments is evident in the *Port Needs Study* descriptions of 23 operating areas. Six generic waterway types were developed to categorize zones within each region examined:

1. open approach (from the sea to the pilot boarding station);
2. convergence (area dominated by converging traffic lanes and channels immediately inbound of an open approach);

BOX 4-1 HIGH WATER ON THE LOWER MISSISSIPPI

Upstream levees hold high water in the river; channel depth increases. The large volume of channeled water increases current speed and turbulence. Control of downbound vessels becomes more difficult in the heavy tail currents. At Algiers Point in New Orleans, the current runs so fast that the river will not safely support two-way traffic, causing the Coast Guard to operate its high-water traffic light. The heavy, turbulent currents transport large suspended sediment loads downstream. Farther down the river beyond the levees and in the delta, the high water spills out into the coastal wetlands, current decreases, and sediment is deposited. Shoals build up in the channel, making frequent maintenance dredging essential to prevent groundings. Sometimes the sediment loading is so heavy that sediment is carried far out into the Gulf of Mexico. The interaction of the gulf and river water below the surface creates a turbulent mixing zone; the water–sediment mixture in this interface more or less attains the consistency of jelly. During these conditions, a ship must literally plow its way through this mixture in order to make the pilot boarding station.



Sandy Hook pilot boat in winter conditions pushing to meet a waiting ship off of Staten Island, New York. (Arthur J. Roche, *United Sandy Hook Pilots of New York and New Jersey*)

BOX 4-2 USING AUTOMATIC RADAR PLOTTING AIDS IN NARROW CHANNELS

ARPA utility for piloting is affected by processing limitations that constrain its effective use in piloting waters. These limitations include radar accuracy of 50 yards under the best conditions; inconsistencies in the size, shape, and position of radar targets; inconsistencies in ARPA solutions due to motion variation; and the inability to obtain solutions during maneuvering situations because steady-state tracking cannot be maintained (Zabrocky, 1992). The collision avoidance feature of ARPA loses its value when vessels meet in very narrow channels. Rapid changes in the motion of the approaching vessel degrade the accuracy of the ARPA prediction. The end-on-end aspect of meeting situations, especially those that require hydrodynamic interactions, further limits ARPA utility.

3. open harbor or bay (generally, an outer harbor or harbor with relatively open water that may contain significant port facilities);
4. enclosed harbor (such as an inner harbor or harbor protected by a breakwater that includes substantial intersections and port facilities);
5. constricted waterway (a narrow channel); and
6. river.

One or a combination of these types may be present in any local port and waterways system. The physical differences among port regions affect marine safety significantly.

The study made use of a per-transit rate weighted by various factors to provide a consistent basis for compensating for differences between ports, a necessity in determining benefits and costs of installing vessel traffic services (VTS). Figure 4-2 reflects the historical casualty rates for VTS-addressable casualties per 100,000 transits, as recorded in Coast Guard and NTSB investigations of marine accidents between 1979 and 1989, and in data on waterborne commerce accumulated by the U.S. Army Corps of Engineers for 1987, which was used as the base year for transit calculations. The rates ranged from near zero for Portland, Maine, and Portsmouth, New Hampshire, to about 213 per 100,000 transits for the lower Mississippi River (Maio et al., 1991). (Annual casualty data are not presented in the study.)

The Coast Guard is developing an exposure data base to provide the resources needed to balance and compare exposure factors for the various ports (Abkowitz et al., 1985; Hantzes and Ponce, 1991). The data from this ongoing effort already have been used by the Coast Guard to compare pilot performance by pilot category (USCG, 1993c). (The results of this assessment are discussed in Appendix D.)

Because of substantial variations in the nature and level of exposure among ports, casualty rates by themselves do not necessarily reveal whether one port is any more or less safe than any other. For example, a ship transit from Southwest Pass at the mouth of the lower Mississippi to Baton Rouge is over 250 miles in length and is under a "points and bends" system of navigation (see Plummer, 1966) for the 230 river miles above Head of Passes (the location in the delta where the river branches into the Gulf of Mexico). For some ships, the transit can take up to 24 hours and result in considerable exposure to the hazards of the route. In contrast, a transit in pilotage waters in the ports of Long Beach and Los Angeles is typically only several miles in length. The nature of transits varies widely by trade and category of vessel in the Port of New York and New Jersey complex, which resembles a large spider covering about 300 square miles of approaches, harbors, waterways, and port facilities. The complex includes three prominent "mixing bowls" with converging and conflicting traffic patterns and strong tidal currents in Hell Gate and Kill Van Kull (Maio et al., 1991; Young, 1992, 1994). There is a general lack of understanding, even within the marine industry, of the complexity of port, waterway, and river operating environments; the nature and variability of risk factors that are present; and vessel behavior in shallow water and confined, asymmetrical channels.

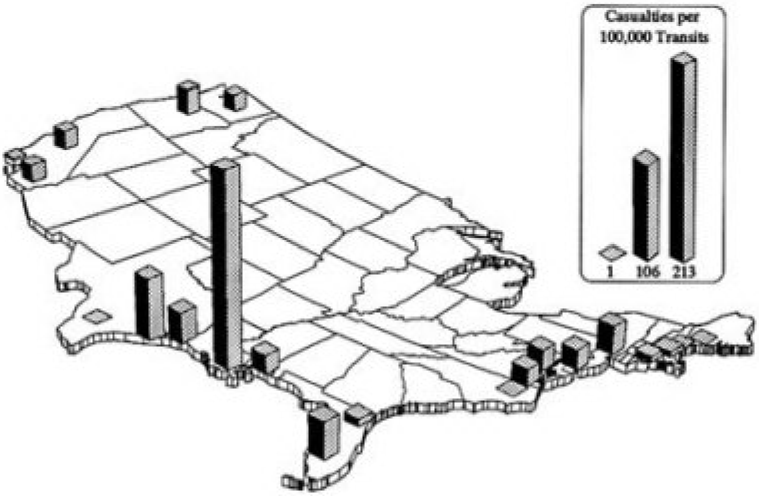


FIGURE 4-2 Historical casualty rates for VTS-addressable casualties (Maio et al., 1991).

Vessel Behavior

Maneuvering a ship under its own power or with assist tugs and maneuvering a tug with tow require considerable skills. The requisite proficiency in ship handling skills increases substantially when vessels are in narrow channels or have small under-keel clearances (Armstrong, 1980; Ferreiro, 1992; Gates, 1989; Hooyer, 1983; MacElrevey, 1988; NRC, 1985, 1992a; NTSB, 1991a; Plummer, 1966). Vessel behavior in confined and shallow waters poses significant challenges to the individual piloting the vessel, whether a marine pilot, the master, or another qualified member of the crew. The challenge is especially great for the marine pilot, who is expected to provide expert shiphandling regardless of prior experience with the vessel or even the category of vessel being piloted (Cahill, 1985; Hooyer, 1983; NRC, 1985). If pilot response to the various forces affecting vessel behavior is not correct, then casualties can quickly follow (Gates, 1989; NTSB, 1991a). These forces, and the shiphandling theory, local knowledge, and practical skills needed to respond effectively to them, are not evident in casual observation.

Forces Acting on a Ship

As a ship moves from deep into shallow water and into constricted channels, the effects of hydrodynamic forces acting on the ship change dramatically, and maneuvering characteristics are greatly affected (Ferreiro, 1992; NRC, 1985). Graff (1993), prepared for this report, discusses the various forces that shiphandlers must understand in order to maneuver their vessels effectively while in pilotage waters. These forces include wind, current, and wave effects in open sea and shallow water conditions; shallow water effects on inertia, maneuverability, heading stability, resistance to headway, stopping distance, and squat and sinkage; and narrow channel effects on vessel control and vessel interactions. Although there many texts and professional papers that discuss these forces, their effects, and responses to these effects, there is no "cookbook" solution to piloting. The study of hydrodynamics has advanced considerably, but there is still much to be learned about hydrodynamic effects on vessel maneuvering in restricted shallow water, especially where there are small under-keel clearances. Therefore, considerable observation and practical experience is necessary for shiphandlers to develop an appreciation for the forces and to develop the capabilities to appropriately respond to their effects.

Controlled Hydrodynamic Interactions

Unlike the situation in aviation, where maintaining separation between aircraft is paramount to safe navigation (Chapter 5), marine navigation in confined channels routinely involves and sometimes requires direct interactions between vessels. Indeed, this is a major distinguishing factor between the marine and aviation operating environments. In some cases, safe passage cannot be accomplished without controlled hydrodynamic interactions between passing vessels (Box 4-3). Hence, what might appear to be a reckless maneuver between two opposing ships may in fact be the only safe way for two vessels to meet and pass. It may be possible, however, to reduce the number of such evolutions through such measures as regulation of marine traffic, although this could cause significant economic effects (Box 4-4).

BOX 4-3 PASSING EVOLUTION IN A NARROW CHANNEL

When two ships meet in a confined waterway too narrow for avoidance of substantial hydrodynamic interactions, they steer directly at each other until they come under the hydrodynamic influence of the other's bow wave. At this point, the rudders are angled to starboard on each ship. The ships are forced apart by the combined effects of the bow wave and the propeller thrust on the rudder. The turn to the right is checked in part by the interaction of bow wave on the starboard side with the channel wall or bank, and rudder angles are applied as necessary to maintain control. Propeller revolutions are increased if additional thrust is needed to maintain control. As the ships pass each other, their sterns are drawn toward the bank (bank suction effect). When each bow clears the stern of the other vessel, pressure on the port bow is decreased. The combined effect of high pressure on the starboard side of the bow and bank suction at the stern causes each ship to sheer to port toward the channel centerline. Right rudder and increased shaft revolutions are applied as necessary to compensate and bring each ship back into the center of the channel. The ships remain under control as the pilots steady them on the channel centerline, although several minor oscillations about the centerline may occur. Precision is required in the timing and correct application of rudder angle and thrust during each element of the maneuver, because there is little to no maneuvering room to recover if an error is made (Ferreiro, 1992; Hooyer, 1983; MacElrevey, 1988; NTSB, 1991a; Plummer, 1966).

Transit Considerations

Risk is significantly affected in piloting waters by the nature of marine commerce and the vessels engaged in it, as well as cargoes carried, length of exposure, and navigation support available both on and off the vessel. The *Port Needs Study* provides a wealth of information on the type and scope of vessel traffic and the nature and quantities of cargoes carried. The study also identified geographic areas where accidents occurred (but did not examine underlying causes). These factors and their interactions are part of the risk equation. However, there is no evidence that they are systematically considered by marine safety authorities in the effort to improve risk management in ports and waterways.

Navigation aids also are a factor in risk assessment. While these aids are intended to reduce risk, they sometimes can have the opposite effect. For exam

BOX 4-4 TRADEOFFS IN ECONOMIC EFFICIENCY AND SAFETY IN PORT OPERATIONS

Vessel meetings resulting in substantial hydrodynamic interactions between vessels may occur by chance, but are also routine operating practices for some major ports and waterways. This is especially the case for some Gulf Coast ports and waterways systems, notably the 46 mile long Houston Ship Channel. The channel is simply not wide enough to support unrestricted two-way traffic. One-way traffic for very large ships could be imposed, as is done voluntarily by marine pilots under interagency agreements for the Sabine waterways and the Calcasieu Ship Channel. However, in the Houston Ship Channel there are no holding areas. Thus, if one-way traffic were imposed, a berth could sit idle until outbound ships cleared the channel and inbound ships could enter and proceed to berth (NTSB, 1991a; Taylor, 1990a,b). The ensuing extensive queuing problems and delays could place Houston at an economic disadvantage in regional and international trade. The extent of queuing problems is demonstrated by a December 1992 marine accident. When a barge sank in the channel after a collision with a cargo ship, the port was closed for several days, and traffic was restricted during salvage operations over several additional days. Movements of over 50 inbound and 10 outbound ships were delayed (Journal of Commerce, 1992c; Taylor, 1992). The marine pilots serving the Port of Houston (and other port regions with similar operating conditions) employ controlled interactions of hydrodynamic forces—the so called "Texas maneuver"—when meeting other large ships in the channel. This practice assists the Houston Port Authority in maximizing the port's economic potential. Increased risk is offset by the expertise of the marine pilots who train in the effective use of this maneuvering technique. However, as a result of a marine accident, the marine pilots in Houston voluntarily limited the combined width of vessels that would be permitted to meet using the Texas maneuver, although not as much as recommended by the NTSB (NTSB, 1991a; Taylor, 1990a). The Houston scheduling example is but one example where risk is influenced by economic considerations. Vessel loading is another major economic consideration common to virtually all but deepwater ports. Every inch of draft means substantially more cargo tonnage can be carried. But every inch of draft also brings the vessel closer to the bottom. Small under-keel clearances in combination with hull form and hydrodynamics can result in erratic vessel behavior, increasing the probability that an accident might occur. Therefore, pilots pay close attention to channel depth and tidal conditions. At high tides, for example, a vessel can carry more draft across the bar or areas where shoaling has occurred. Yet, how a specific vessel may react under different loading conditions and small under-keel clearances is usually not well known. A difference of just a few inches can cause a previously well-behaved vessel to become uncontrollable (Gates, 1989; Plummer, 1966). Since waterways lag years behind ships in improvements (NRC, 1992a), economic pressures to increase loading, pilot acquiescence, and lack of waterways management can combine to increase risk.

Maneuvering during meeting situations in restricted shallow waters with small under-keel clearances, such as is common in the Houston ship channel, necessitate use of hydrodynamic interactions to effect a safe passage. Also required are highly-developed shiphandling skills and precise timing of conning commands by the marine pilots. (*U.S. Coast Guard*)

Simulation training using manned-models enables mariners to practice "hands-on" use of hydrodynamic forces during maneuvering. (*SOGREAH Port Revel Centre*) ple, radar is widely credited for reducing strandings and collisions. However, there are also numerous cases where "radar assisted" collisions occurred because mariners focused too much attention on the radar picture or incorrectly interpreted radar information (Aranow, 1984; Cahill, 1983; CAORF Research Staff, 1978; Hayes and Wald, 1980; NTSB, 1972). The implication is that technological advances can ameliorate some risks while introducing others.

ISSUES TO BE ADDRESSED BY QUANTITATIVE RISK MANAGEMENT

Data Limitations

Considerable marine safety data are collected under protocols established by the Coast Guard. Although these data are useful, they do not provide the resources necessary to assess trends related to vessel construction, outfitting, manning, technical systems, and maintenance, or to develop a full understanding of all safety needs (NRC, 1990a). Also, a large number of small-scale, localized incidents occur that, with few exceptions, are not tracked by marine safety authorities. The potential for small-scale incidents to develop into marine casualties is neither well understood nor addressed in most waterways management activities, except where VTS systems have been established (Young, 1992, 1994). Until data designed to support quantitative assessment are available that could help guide safety initiatives intended to reduce operational risk, such assessments will remain difficult to conduct and will be based on historical data.

Causal Factors in Marine Accidents

A few reports are available that examine task performance problems and situational factors in marine accidents. Some found that different task performance problems are associated with different types of marine accidents (Cahill, 1983, 1985; Gates, 1989; NAS, 1976; Paramore et al., 1979; Smith et al., 1976). Although vessel and navigation technologies have changed since most of these reports were prepared, many aspects of navigation and piloting remain much the same, partly because of reliance on traditional operating practices while in pilotage waters. Therefore, some of the earlier findings remain relevant today. The committee examined key findings from these studies for relevance to the current operating environment. The results are presented in the following sections. Also available were a number of important safety studies; marine accident reports; and other analyses, testimony, correspondence, and anecdotal information pertaining to navigation and piloting practices. A summary of these studies pertaining to pilotage and what can be learned from them is provided in Appendix D.

Communications

Stoehr (1977) concluded that the bridge-to-bridge radiotelephone was a very effective anti-collision device on inland waterways. Paramore et al. (1979) concluded that a parallel degree of success was not evident in harbor areas. Since then, VHF bridge-to-bridge voice radio communications has become universal for domestic and foreign trade commercial vessels. Marine pilots report that harbor safety has improved substantially as a result. However, bridge-to-bridge communications are not without problems. For example, use of separate VTS frequencies (in ports having a VTS) to provide navigation information increases the communications load on the bridge team and pilot, even if the VTS assumes or reduces radio guards (monitoring) on other government-required frequencies.

Voice radio use increases during periods of reduced visibility. This phenomenon can quickly lead to overloading of the bridge-to-bridge radio channel, especially in harbors and congested waterways at the time when radio communications are most urgently needed (Ives et al., 1992; Walsh, 1993; Young, 1994). The network is further pressured by the widespread availability of VHF radiotelephones to the commercial fishing industry and recreational boaters, and occasional unauthorized use of frequencies reserved for bridge-to-bridge communications. Thus, although communications can be said to have improved, they are overloaded at times. Development of alternative means of communications, such as electronic data transfer of traffic and position information, would seem to offer a viable means of sustaining, and perhaps improving, the safety benefits achieved through vessel-to-vessel and vessel-to-VTS communications (Ives et al., 1992; Martin, 1992b; Young, 1994).

Navigation Technology

Building and maintaining shiphandling skills is a never-ending training requirement. To the degree that interpretation of vessel response is a problem, real-time precision positioning systems, real-time environmental information, and automated decision aids potentially can be applied to reduce the potential for human error. Electronic charting systems and Electronic Chart Display Information Systems (ECDIS), in particular, hold tremendous promise for improving vessel navigation and piloting. But with the introduction of new technology come new validation requirements and training needs (Chapters 6 and 7). If history is any guide, there will also be a proliferation of different equipment configurations, inhibiting the ability of marine pilots to maintain familiarity with all of them. Thus, risk could be increased if the introduction of new technology is not planned and implemented carefully, particularly with regard to implications for training needs and operating practices.

The widespread introduction of radar is instructive in this regard. Paramore et al. (1979) identified radar-related problems, including limits in design capabil ities of equipment, poor equipment-operating condition, inadequate operator recognition of when to use available equipment, and inadequate operator skills for using equipment effectively. Radar technology has improved substantially since 1979, including development of reliable ARPA systems (for coastwise and ocean transits) and daylight radar presentations. Nevertheless, marine pilots report that the substantial variation in equipment configurations and capabilities, particularly with the availability of advanced digital features, sometimes makes radar operation difficult. There are simply too many configurations for individual pilots to remain familiar with all of them despite the availability of courses in radar plotting (a manual radar-plotting course is required for renewal of mariners' licenses and for pilots' licenses or endorsements). ARPA systems are especially varied and not suitable for manual plotting. Furthermore, marine pilots and docking masters in some operating areas have limited incentive to acquire familiarity with ARPA systems because of the limitations of such systems noted earlier.

The difficulty of maintaining familiarity with all forms of technology can be expected to grow as automatic dependent surveillance (ADS), electronic charting systems, including ECDIS; integrated bridges; and other high-technology systems begin to proliferate aboard ships and as bridge teams become smaller. At the same time, training requirements for bridge teams will change, probably becoming more stringent, and most likely requiring individuals comfortable with high-technology systems. This change may necessitate recruitment of individuals with advanced education at the same time that seafaring careers are losing popularity because of the work demands placed on merchant crews and the lack of opportunity to relax while a vessel is in port.

Shore- and Waterway-based Navigation Support Services

An alternative to onboard systems for addressing causal factors in piloting accidents is the use of traditional off-ship aids to navigation and shore-based traffic support. Traditional aids to navigation such as buoys continue to be important (Ramaswamy and Grabowski, 1992). They can be improved to facilitate visual acquisition and use. Use of shore-based navigation support systems such as VTS is growing slowly but cannot replace effective performance by masters, bridge personnel, and marine pilots. The effectiveness of shore-based systems in offsetting human errors such as those found in collisions, rammings, and groundings is an open question. VTS can make a positive contribution, but there is also the potential for "VTS assisted" accidents (CCG, 1984, 1988, 1991c; EC, 1987; Herberger et al., 1991; Ives et al., 1992; Maio et al., 1991; Young, 1992, 1994).

Data on Pilotage Risk

Pilotage is a response to risk that, if effective, reduces the probability of an accident. As pilotage is already an expert service, only incremental improve ments may be possible through improved training, such as preparation for using emerging navigation technology. Regardless of how good pilotage may be or where fault may lie, pilotage often takes center stage when an accident occurs; the effectiveness of shiphandling and position-keeping are the first targets of efforts to determine why an accident occurred. The person piloting the vessel, whether a marine pilot, master, or vessel officer, is a discrete, recognizable entity upon which to focus. Technical or mechanical problems such as steering gear failure also may be readily identifiable. But underlying causal factors, particularly deficiencies in professional development and human performance, are difficult to discern, even to trained marine accident investigators. Casualty data have not been adequate to support this task (NAS, 1973, 1976, 1981; NRC, 1990a, 1991a). Most examinations of the safety records of marine pilots have relied on these data and have employed narrow analytical methodologies to establish points of view (Appendix D). Lacking convincing research, discussions of pilotage usually devolve into philosophical debates rather than rigorous analysis of risk, task performance, and technological factors. Analysis of these issues could help identify actions that might improve proficiency and performance of pilots, vessel navigation and maneuvering, and related waterways management.

Controversy Over Pilot Safety Performance

The controversy over pilotage was introduced in Chapter 1; safety aspects of the controversy are summarized here. Specific issues pertaining to safety are pilot safety records (Booz, Allen and Hamilton, 1991; Journal of Commerce, 1989, 1992a; Leis, 1989, 1992; Neely, 1992; USCG, 1993c), oversight (principally pilot discipline; Ashe, 1984; Crowley, 1991; Journal of Commerce, 1992a; Nadeau, 1992; NTSB, 1988a; Parker, 1988; Quick, 1992), and economics (including pilotage rates and competition for pilotage business; Journal of Commerce, 1992a,b; Wastler, 1992a). When pilot safety records are discussed, economic interests usually are lurking below the surface. Some observers argue that where pilot groups compete, all pilotage business should be handled by the safer group, and governance should be modified to effect this change. This concept has fomented considerable controversy (Abrams, 1992a,b; Journal of Commerce, 1992a,b,c,d; Wastler, 1992a,c). Economic arguments seem to coincide with the presence of larger ships and a lessening number of port calls (reducing pilotage business). Also at issue are actual or potential shifts in shipping business between competing ports. Such shifts affect pilotage business (Abrams, 1992b); the nature of port-specific pilotage provides virtually no flexibility for mobility between pilotage districts. There is also very strong and continuing debate over how much pilots should be paid for their services (Journal of Commerce, 1992a; Wastler, 1992a). The committee, in the present report, did not address the fairness of pilotage rates other than to observe that pilots are experts deserving of suitable compensation for their services and that rates need to accommodate the pilotage infrastructures insofar as they are required to support essential pilot services (Abrams, 1992b; DOT, 1988; Sherwood, 1992). Fairness of rates is a matter for local determination based on circumstances peculiar to each pilotage route. Considerations normally include infrastructure requirements, hazards peculiar to the profession (especially boarding at sea), and recognition of the expert services that are provided.

IMPROVING RISK ASSESSMENT, MANAGEMENT, AND COMMUNICATION

The need for improved safety data and systematic performance assessment has been identified in previous National Research Council reports (NRC, 1990a, 1991a). "Fully effective administration of safety programs depends on adequate data resources. Without reliable and statistically valid data, safety shortcomings cannot be identified with clarity, and once safety programs are in place, they cannot be evaluated to determine if they are effective and whether resources committed to safety are being used wisely" (NRC, 1991a). In addition, reliable data on the range of identified risk factors is needed to support complete risk assessments. Alternatives for development of data on risk and exposure that are identified in the following sections are intended to supplement recommendations of prior NRC reports.

Establish a Near-Miss Reporting System

Valuable early insight on actual or potential trends or problems can be obtained through routine recording and analysis of data on:

- marine accidents;
- unusual events (such as loss of propulsion, steering system failures, and near misses that do not qualify as reportable casualties);
- marine events (such as regattas);
- fires (including fires ashore detected through VTS surveillance equipment); and
- other incidents of interest to waterway administrators (Young, 1992).

Although administration of a system data base is best handled by a single organization in order to maintain data integrity, cooperative near-miss reporting is nevertheless a possibility. New technologies offer the potential for collecting key data as part of existing government and commercial operations. Information could be recorded and maintained by a VTS, a harbormaster, Coast Guard Captain of the Port office, marine exchange, pilot dispatch office, or port authority operations office, if such offices were equipped and staffed for this purpose. Improvements in collection and analysis appear feasible using advances in integrated electronic display technologies and software (such as automated tracking capabilities) to automate collection of key data as it is processed during operations. Once data sets are automated, pre-formatted reports and options for supplemental sorting and presentation (including graphics) could offer a very convenient means to support program assessment and administration. Analysis of acquired safety performance data and application to program analysis, planning, administration, and implementation are also feasible at the port level using automated relational data bases and computer graphics. These activities could either be integrated with VTS computer-based operating systems or accomplished off line using desktop computers and software.

Implementation plans would need to address such factors as information sharing between the port community and the Coast Guard, potential liabilities, and fairness in characterizing the performance of individual vessels or vessel classes. An earlier attempt at developing and implementing such a maritime near-miss reporting system failed when participants were wary of attribution difficulties. Surmounting these difficulties would be important in implementing an effective near-miss reporting system.

Establish an Exposure Data Base

Limited information is available on traffic flows, seasonal variations, daily variations, trouble spots, trouble conditions (such as problems in an anchorage), problem vessels, commodity flows, effectiveness and utility of navigation support systems such as VTS and onboard electronic equipment, casual factors, and other information essential to refinement of operations and system planning. Some of this information already is collected in varying degree but is not widely used to plan or guide traffic regulation operations or safety programs. This information could be combined in a reliable data base, such as the Coast Guard's prototype exposure data base, which would facilitate identification and analysis of risk and exposure across a wide range of variables. Risk and exposure data could be consolidated to facilitate their use in risk analysis.

Establish a Comprehensive Risk Assessment Program

Information is of no practical value unless it is effectively used. A continuing risk assessment program could be established at the national level. The program would draw on information from near-miss reporting; national and worldwide exposure databases; and relevant quantitative risk assessment studies, including those based on modeling performed as part of permit applications and other activities requiring risk assessment and other appropriate safety information. The purpose would be to provide near-term capability to detect trends in shipping that affect marine, public, and environmental safety and U.S. economic interests. The program also would provide essential data for planning improvements to the marine traffic safety system, setting priorities for regulatory initia tives, and determining benefit–cost relationships for possible regulatory requirements and government programs.

Databases would need to be constructed to support quantitative risk assessments, including valuation of consequences, comparisons of alternative strategies, and provision of absolute risk values. Such an effort would require coordination among worldwide regulatory, classification, and insurance interests to ensure that the data base was large enough to provide statistically significant results. Implementation would require long-term commitment of resources by the Congress, the Department of Transportation, and the agency designated to conduct the program.

5

Marine Traffic Regulation

SUMMARY

Marine traffic regulation following the aviation model often is suggested as a way to improve navigation safety. There are more similarities between the marine and aviation operating environments than commonly perceived. However, the differences preclude the aviation system from serving as an exact or even close operational model for marine traffic regulation, although lessons can be learned and adapted from the aviation experience. Furthermore, although marine traffic regulation analogous to the aviation model is technologically possible, it is not operationally feasible as the marine navigation and piloting system is organized and operated. Extensive changes would be needed nationally and internationally in system organization, vessel outfitting with navigation equipment, professional development of mariners and traffic regulation personnel, vessel crewing, and marine operating practices. Nevertheless, full-mission vessel traffic service (VTS) systems, where in operation, provide an improved organizational structure for interdependent decision-making aboard the vessel and in the waterway. VTS operations also provide safety oversight for vessel transits in the VTS service area.

Major factors that distinguish the marine environment are the numerous variables that must be integrated and accommodated in vessel maneuvering. These variables include frequent hydrodynamic interactions of vessels with other vessels and with the physical features of channels and other waterways. The port and waterways operating environment is somewhat more forgiving than that found in aviation in that even major marine accidents or failures of primary pro

pulsion and steering systems usually do not immediately result in loss of life or the vessel, but the timing of decision-making and maneuvering can be just as critical as in aviation. Active traffic direction already is practiced in the marine sector on a very selective basis in the form of shore-based pilotage, normally provided by marine pilots in cooperation with a VTS. In addition, traffic is managed in ports and waterways through control of time and space in which vessel movements occur, usually on a case-by-case basis in the United States but more systematically in some major foreign ports. Broader application of directed maneuvers and traffic management is constrained by numerous factors including the complexity of marine operations; the lack of precision navigation capabilities on most vessels in terms of equipment and related operator skills that would permit strict adherence to assigned paths; the lack of complete, centralized information about each vessel, including maneuvering behavior, and about operating conditions both on the vessel and in the waterway; the difficulty in acquiring and ensuring sufficient breadth and depth of nautical and traffic-control knowledge and skills among shore-based traffic regulators; and lack of a common language for navigation communications among bridge personnel, marine pilots, and other vessels.

The Coast Guard's port-level, nationwide operational infrastructure—including existing VTS systems, perhaps linked with marine pilot dispatch offices, marine exchanges, and port authorities—could be adapted to form a national marine traffic regulation network modeled in concept after the National Airspace System, with or without traffic management or positive direction of vessel maneuvers. Alternatively, government and privately operated VTS and VTS-like systems could be expanded to improve waterways management and safety oversight.

REGULATION OF MARINE AND AIR TRAFFIC

Marine traffic regulation, in the strict sense modeled by the air traffic control system, is not practiced anywhere in the world. Whereas all aircraft operating under instrument flight rules (or visual flight rules in designated airspaces) are controlled relative to flight plans and monitored to ensure compliance and clearances by an air traffic controller, there is no overarching system for controlling ship movements. Various types and levels of traffic regulation are in place but not in the same form or to the same degree as in aviation. There is one notable exception—the occasional practice in Rotterdam of a marine pilot using the communications capabilities of a vessel traffic center (VTC) to direct the movements of a ship piloted by a fellow marine pilot under very difficult operating conditions (Herberger et al., 1991). The possibility of enhancing marine traffic regulation in other settings often arises, however, and, when it does, references to the aviation system closely follow.

In accordance with that theme, this chapter explores the marine traffic regulation concept using the framework of the aviation model. By comparing the aviation and marine environments, the chapter examines whether some or all of the operating concepts and practices exhibited by the U.S. national air traffic control system might be adapted for marine traffic. Marine traffic regulation concepts and alternatives are presented, including expanded use of government-and privately operated VTS and VTS-like systems of various scale that have been established in about 20 U.S. ports and waterways (Figure 5-1).

COMPARISON OF AIR TRAFFIC CONTROL AND MARINE TRAFFIC REGULATION

Overview

The need for an air traffic control (ATC) system that is highly reliable is driven by the unforgiving operating environment. The requirement for an ATC system arose because of the demand for flight operations during periods of limited visibility, where "see and avoid" was no longer effective. The main functions of ATC are to issue clearances to aircraft based on their desired flight plan and the existing flight plans of other aircraft and to monitor the air traffic to ensure compliance and clearance. The consequences of onboard system failure can be catastrophic, as aircraft and the lives of passengers are totally dependent upon reliable system performance. Furthermore, the high speeds at which interactions occur increase the importance of timely and correct decision-making. Great precision is required for safe operations, and there is limited opportunity to recover from operator error or from failure of aircraft or control systems. In contrast, while an aircraft and its occupants are in extreme danger if propulsion is lost in flight, the danger to a ship and persons on board usually develops less quickly. In a brief time after system loss, the vessel may be able to anchor, obtain external assistance (such as tugs), restore failed systems, or warn off conflicting traffic. Further, even where time is a critical factor in maneuvering (as it often is in confined pilotage waters) and a collision or grounding occurs, destruction and loss of life usually are not immediate. On the other hand, the potential for widespread consequences, especially to the natural environment, is generally greater in marine transportation than in aviation due to the carriage of large quantities of petroleum or other hazardous and dangerous cargoes.

Another key difference between the two environments is that air traffic control is mainly the product of the latter half of the twentieth century, when technology has been greatly advanced, whereas marine operations are steeped in tradition and are highly fragmented from a systems perspective, affecting the acceptance of technological change. Partly as a result, public policy calls for—and the general public expects—an air traffic control system that maximizes the potential for safety. Marine traffic regulation has received considerably less at

FIGURE 5-1 Vessel traffic services and similar operations serving U.S. waters. KEY: VTS locations and, in italics, operating organizations (GAO, 1993b; Ives et al., 1992). **1** Vancouver VTS Centre (*Canadian Coast Guard*). Serves U.S. waters of Haro Strait and Straits of Georgia by bilateral agreement between the United States and Canada; **2** Puget Sound VTS (*U.S. Coast Guard*). Serves Canadian waters in Straits of Juan de Fuca by bilateral agreement between the United States and Canada; **3** VTS San Francisco (*U.S. Coast Guard*); **4** Ports of Los Angeles (*Los Angeles City Pilots*) and Long Beach (*Jacobsen Pilot Service*). Voluntary private VTS systems. VTS for harbor approaches has been established by the Marine Exchange and includes joint operation with U.S. Coast Guard; **5** Aloha Tower (*State of Hawaii, Department of Transportation*). Controls access to Honolulu Harbor; **6** VTS Prince William Sound (*U.S. Coast Guard*); **7** VTS Houston-Galveston (*U.S. Coast Guard*); **8** Sabine Waterways (*Sabine Pilots*). Voluntary traffic system operated by the pilot association under an agreement with other organizations in the local maritime community; **9** Lake Charles VTS (*Lake Charles Pilot Association*). Voluntary traffic system operated by the pilot association for the Calcasieu Ship Channel under an agreement with other organizations in the local maritime community; **10** Marine Safety Office, Morgan City (VTS for Berwick Bay area)(*U.S. Coast Guard*); **11** Algiers Point Traffic Light (*U.S. Coast Guard*). Operated during high water conditions. VTS New Orleans was disestablished in 1987; **12** Southwest Pass (*Associated Branch Pilots*). Voluntary, privately operated VTS-like information service; **13** VTS Lousville (*U.S. Coast Guard*). Operated during high water conditions; **14** Entrance to Chesapeake Bay (*Virginia Pilots Association* and *Association of Maryland Pilots*). Voluntary, privately operated VTS; **15** Entrance to Delaware Bay (*Pilots Association for the Bay and River Delaware*). Voluntary, privately operated VTS;

Operator's console, Vessel Traffic Service New York. Equipment in the vessel traffic center was upgraded in 1994 to the configuration shown.
(Dave Hill, *USCG Vessel Traffic Service New York*).

16 Chesapeake and Delaware Canal (*U.S. Army Corps of Engineers*). Mandatory traffic system for transit of the canal; **17** VTS New York (*U.S. Coast Guard*). Reestablished in 1991; **18** Cape Cod Canal (*U.S. Army Corps of Engineers*). Mandatory traffic management system for transit of the canal; **19** VTS Massena (*Saint Lawrence Seaway Development Corporation*); **20** VTS Sault St. Marie (*U.S. Coast Guard*); **21** VTS Sarnia (*Canadian Coast Guard*). Serves U.S. waters in the Detroit and St. Clair rivers by international agreement between the United States and Canada; **A** The U.S. Navy operated naval access control systems for the entrance to certain naval ports including Little Creek, Virginia, and Pearl Harbor and controls access to naval firing ranges in U.S. waters; **B** The U.S. Army Corps of Engineers queues traffic through its locks and dams throughout the inland waterways system, including the Chittendon (Ballard) Locks in Seattle, the Columbia and Snake River systems, and the western rivers.

tention. However, interest is growing nationally and internationally in systematic local and regional traffic management due to a recent series of noteworthy tanker accidents with great spillage of oil (CCG, 1992; Corbet, 1992; EC, 1987; Herberger et al., 1991; Ives et al., 1992; Maio et al., 1991; Mizuki et al., 1989; OSIR, 1993a,b,c).

Federal Marine and Aviation Infrastructures

Local port authorities and other port facility owners in the United States may sponsor local channel improvement projects, provide shoreside infrastructure, and be involved in vessel scheduling with shipping companies and agents. But port authorities seldom are involved in managing actual operation of the waterway systems that provide access to their ports—this is principally a federal responsibility. The lack of consolidated ownership of port facilities and lack of a single coordinating authority for port operations can be a complicating factor in vessel traffic management by other than the federal government whose authority covers the full extent of navigable federal waters.

The federal government provides national infrastructure, with administrative and operational capabilities and enabling authorities for traffic control, for both aviation and marine sectors. The Department of Transportation (DOT) administers the National Airspace System through the Federal Aviation Administration (FAA). The DOT administers port safety, port security, aids to navigation, and other activities to keep ports and waterways open and safe through the U.S. Coast Guard. The U.S. Army Corps of Engineers in the Department of the Army is responsible for construction, operation, and maintenance of federal navigation projects for inland waterways, canals, locks and dams (including traffic queuing functions), and federal channels in coastal ports.

Substantial public resources are committed to traffic systems in both modes of transportation. Cost recovery by the federal government also is substantial for both modes, although the exact figures depend on which federal taxes, revenues, and sponsor cost-shares for construction projects are counted (see CBO, 1992).

The National Airspace System

The U.S. air traffic control system provides virtually universal coverage of controlled airspace (Illman, 1993; Nolan, 1990). Air traffic control services include:

- flight service stations that help pilots plan their flights;
- airport traffic control towers (at about 400 airports) for direction of landings and takeoffs extending to several miles from the airport, and ground control;
- terminal radar approach control (TRACON) facilities at busy airports

(188 nationwide) that monitor aircraft movement within about 30–50 miles of the airport after handoff from or handoff to enroute control and handoff to or from the tower controller;
- air route traffic control centers (ARTCC) (22 nationwide) that monitor and guide aircraft when handed off from or to a local TRACON, towers, or another ARTCC; and
- a central flow control facility that is responsible for monitoring and managing aviation traffic flows nationwide.

All of these services are operated by the FAA,[1] and all are staffed by specially trained federal employees. Airport infrastructures generally are not considered part of the airspace system, as most are operated by state or municipal governments, but air and surface traffic at airports are part of the FAA system. The electronics suites supporting the airspace system are generally quite sophisticated, although not fully adequate under certain conditions, particularly when traffic overloading occurs, and latest-generation equipment is not available at all locations. Additionally, extensive pre-planning of scheduled air carrier service is provided by major carriers for their flights. Also provided is real-time enroute support, referred to as flight control, that complements air traffic control services. This company-based planning is a principal resource for keeping air carrier service within air traffic control capacity and includes rescheduling and cancellation of flights if delays develop, such as might occur due to adverse weather affecting landings and takeoffs.

The air traffic control system provides a highly structured framework within which precise rules, procedures, and highly reliable communications links allow for interdependent decision-making by highly skilled personnel dispersed across the entire network. Specific features that, collectively, enable this distributed decision-making system to control air traffic effectively are shown in Box 5-1. The system can be characterized as highly coupled. There also is a near-miss reporting system to facilitate identification, assessment, and correction of specific and systematic problems. Individual features appear to be matched to current operational needs and safety objectives, although substantial equipment improvements are needed. The FAA began a major long-term modernization program in 1981 that is still in progress (CBO, 1992; Nolan, 1990). (Major high-technology components of the program were canceled by the FAA in mid-1994, because of rapid evolution in technology, reported flaws in specialized software, opposition by traffic controllers to replacement of paper strips by electronic data for flight tracking, and major schedule delays and cost increases [Li, 1994; Hilzenrath and Burgess, 1994; Weintraub, 1994; Weintraub and Burgess, 1994].)

[1] The Clinton Administration began action in mid-1994 to shift responsibility for operation of the National Airspace System from the FAA to a government corporation, because of alleged bureaucratic inefficiencies in the FAA's administration (Hilzenrath and Burgess, 1994).

BOX 5-1 CENTRAL FEATURES OF THE AIRSPACE SYSTEM SUPPORTING EFFECTIVE DISTRIBUTED DECISION-MAKING

- a single governing authority exercising traffic system administrative and operational control;
- high-reliability systems (aircraft- and ground-based flight-control coordination);
- universal standardized instrument flight rules and procedures;
- operating environment that permits use of a universal language (a highly stylized, succinct vocabulary in English);
- direct traffic control over the aircraft, including assignment of flight paths and directed maneuvering;
- controlled access to airspace subject to air traffic control;
- means to monitor and prevent interaction between aircraft, including separation in horizontal and vertical planes;
- real-time position fixing on board aircraft and in the air traffic control center;
- aircraft maneuverability that permits strict adherence to assigned paths;
- real-time and enroute environmental data for landing approaches and takeoffs;
- environmental constraints to prevent or reduce exposure to hazardous operating conditions;
- well-developed standard procedures;
- rigorous professional development requirements and programs for aviation pilots and air traffic controllers,
- a professional cadre of air traffic controllers;
- technology that provides more time for decision-making in conjunction with management measures such as conflict monitoring, so that effective action can be taken by pilots;
- a near-miss reporting system for early detection and correction of control-system problems; and
- company-provided dispatch (flight control) and technical support operations for scheduled air carriers.
- Sources: Illman, 1993; Nolan, 1990.

Although each of the features listed in Box 5-1 is fundamental to successful functioning of the basic system, technology that enables timely decision-making and provisions to ensure effective human performance appear to be crucial in maintaining system integrity and preventing accidents. The high speed at which interactions occur demands that decisions be made as early as practical and feasible to allow sufficient time for controllers to detect and interpret actual or potential problems, communicate the situation and needed corrective measures to the aircraft (including maneuvering orders), and for both pilots and controllers to take whatever subsequent actions are appropriate.

Applying the Aviation Model to Marine Transportation

Ensuring traffic safety requires a multidimensional solution. Seventeen features associated with the National Airspace System were identified that contribute to its success (Box 5-1; Braff et al., 1993). Physical separation, advance forewarning of danger, and pilot and controller proficiency appear to be especially important in preventing accidents.

Traffic separation is an essential line of defense against mid-air collisions. The three-dimensional operating environment once enroute provides great flexibility for multiple and layered flight paths. Although traffic separation for commercial vessels is feasible in open waters, the geographic and hydrographic features of most harbors and waterways, as well as the maneuvering requirements, often preclude two-way separated traffic lanes.

As in aviation, the key to preventing marine accidents by outside intervention is to ensure forewarning of danger. The advance notice must be sufficient that corrective or evasive action can be taken to maintain adequate separation while also increasing the range of alternative actions available to resolve actual or potentially dangerous situations. Marine traffic controllers (such as VTS operators) would have to acquire sufficient professional knowledge and skills to perform the same functions as an air traffic controller. If this were feasible, which is an issue of considerable national and international debate (Ives et al., 1992), then other questions would arise. In particular, how much separation and time would be needed to interpret that a dangerous situation was developing, to communicate this information to the involved vessel or vessels, and for the person piloting the vessel(s) to evaluate the information received and take the necessary corrective or evasive action? The professional knowledge, skills, and proficiency of masters, mates, and pilots, and their abilities to take corrective action was addressed in the preceding chapters. A human systems perspective on these abilities is presented in Chapter 7.

Whether the aviation model would work in the marine environment to support these actions and the underlying traffic control concept depends on:

- whether and to what degree the factors that govern success in the National Airspace System are relevant to marine transportation;
- identification and assessment of governing factors peculiar to the marine environment that cannot be handled by the air traffic control model; and
- an assessment of capabilities to develop and operate a system of marine traffic regulation that incorporates the features of the air traffic control system.

Adapting the aviation concept to marine transportation is discussed as an alternative later in this chapter.

Comparing the Aviation and Marine Operating Environments

On cursory observation, the marine operating environment appears to be substantially different from the aviation environment. Yet, the physical forces involved are more similar than they might appear. The person piloting an aircraft or a vessel must understand the craft's behavior relative to the physical forces present and respond to them. Some of the factors that must be considered by the person piloting a vessel include aerodynamics, hydrodynamics, environmental conditions, channel configurations, navigation by all units in a two-dimensional plane, vessel loading effects on controlling vessel movement, and traffic congestion. In fact, there are many similarities and some differences between the two environments. Table 5-1 characterizes these differences and similarities. The table is derived from Nolan (1990), the principal text on the fundamentals of air traffic control, and two papers prepared for the Committee on Advances in Navigation and Piloting—Braff et al. (1993), which examined each feature and identified implications for marine traffic regulation, and Ives et al. (1992), a detailed assessment of vessel traffic services.

Additional Considerations in the Marine Setting

Liability issues have yet to be resolved concerning VTS intervention to influence operator and vessel behavior, let alone traffic control. The master still is responsible for the safe navigation of the vessel. Under certain circumstances, the master may be unable to comply with an order issued by a waterway manager or port-safety official without endangering the vessel. For example, if a Coast Guard Captain of the Port (COTP) were compelled to suddenly close a channel due to a breakdown or a marine accident, the person piloting the vessel that has already committed to a transit may be unable to slow down, stop, anchor, or turn around.[2] In such cases, obeying the order might be more dangerous to the vessel than proceeding; yet the master or pilot might feel obliged to obey the order, because it came from the Coast Guard. It can be argued that such decisions, and the shiphandling judgments required to execute the ensuing actions, should be left to operators aboard the vessel, because that is where the ultimate responsibility lies. In any event, these types of cases could demand a continuing exchange between the vessel and waterway management authorities (perhaps through a VTS, where present) rather than an absolute decision. The circumstances could be further complicated by:

[2] For example, a loaded tanker with a strong fair (following) current in a narrow channel might not be able to stop and hold position even with tug assistance, or to anchor or turn around. An intentional grounding in soft bottom might be the best alternative, but this could subject the master or pilot to disciplinary proceedings. If the bottom were hard, then the only other option might be to proceed.

TABLE 5-1 National Airspace System Features Compared in the Aviation and Marine Sectors

System Feature	Aviation	Marine
Governing authority	National Federal Aviation Administration (FAA) infrastructure; national enabling authority for traffic control measures. (Shifting responsibility from FAA to a government corporation is under consideration.)	National Coast Guard infrastructure; national enabling authority for traffic regulation measures
High reliability systems	Available for aircraft and flight control systems. Air traffic control equipment varies from older equipment to state-of-the-art computer hardware and software.	Available on a highly selective basis.
Universal rules and procedures	Required use for all aircraft operating under instrument flight rules and for entry into controlled space by visual-flight-rule aircraft; active monitoring for aircraft under instrument flight rules.	Use of self-enforcing rules of the road required; unit-by-unit application; selective monitoring; enforcement occurs after-the-fact.
Universal operating language and use protocols	Highly stylized language required for aircraft operating under instrument flight rules.	Stylized language available but not required or in wide use.
Direct traffic control	Standard practice for aircraft operating under instrument flight rules.	With rare exceptions, not practiced.
Controlled space	Strict rules govern entry by all aircraft in controlled airspace	Space management by the Coast Guard on an infrequent and selective basis for federal waters; queuing of traffic by Army Corps of Engineers for transits of certain canals and

System Feature	Aviation	Marine
Controlled space (continued)		locks; queuing of traffic practice on a limited basis by marine pilots in several ports; use of waterways by recreational craft generally not regulated except for passage of locks.
Physical separation	Standard practice. Physical interactions with other units precluded by multiple, layered flight paths in three dimensions.	Standard practice for commercial traffic using prescribed traffic lanes; not practiced in confined waterways generally. Hydrodynamic interactions between vessels are not only a common occurrence but also sometimes are necessary in order to maneuver safely during meeting situations in narrow channels.
Real-time accurate navigation capability	Very precise capability available for heavily trafficked approaches and landings. Continental and intercontinental navigation are less precise.	Technology available but standards still under development; limited but growing commercial use; digitized charts not available for all waters; bathymetric data vary according to collection methods and in few cases provide comprehensive bathymetric profiles. Navigation aboard most vessels relies on manually plotted positions and individual interpretation of electronic data such as radar and loran.

System Feature	Aviation	Marine
Adherence to precise paths	Within existing aircraft operating capabilities.	Possible for routes without shallow water effects using real-time, computer-assisted positioning and steering aids, but requires highly controlled conditions; not widely practiced; reliability not proven for unassisted maneuvering of large vessels in narrow channels with small under-keel clearances.
Real-time environmental data	Available on request.	Reliable predictions of tides and currents available for most locations; real-time tidal gauges not widely available; real-time information on local episodic events not precise.
Environmental constraints on operation	Well defined environmental parameters used to prevent or reduce exposure to hazardous operating conditions.	Operating constraints infrequently imposed for environmental conditions accommodation of environmental conditions left to judgment of master or marine pilot.
Standard procedures	Well defined and extensively used.	Rules of the road are well defined for interactions between two vessels; procedures for multiple-vessel maneuvering situations are less precise. International operating guidelines are available but not used consistently.

System Feature	Aviation	Marine
Standard procedures (continued)		Communications protocols vary by region, local practice, and marine sector. General procedures for vessel movements and communications exist where VTS systems are installed and modified naval communications protocols are practiced.
Rigorous training, certification, and licensing requirements for pilots and controllers	Standard practice. Single licensing authority (FAA) for U.S. pilots. National professional development and licensing requirements and programs. Extensive proficiency certification, although qualification requirements vary by category of service (e.g., large commercial jet, commuter aircraft). Pilots of foreign aircraft must meet standards prescribed by bilateral agreements between their country and the United States.	Marine pilot training varies by federal and state jurisdiction. Single licensing authority (Coast Guard) for U.S. masters and mates; proficiency validation or assessment limited to radar observer's certification for some licenses. Master training varies by flag-state and operating company requirements. VTS operator (controller) training varies by VTS functions, objectives, and operating authority, and it is conducted locally.
Professional controller staff	Highly structured organization. Permanent long-term employees.	Varies by VTS; Coast Guard assignments are 3-4 years.
Technology-based decision aids	Available.	Available in prototype only.
Near-miss reporting system	National system operated by FAA; facilitates identification of operational problems and correction.	No federal program; near-miss records are maintained by some VTS facilities and at least one state pilot authority but not routinely analyzed to identify systemic problems.

System Feature	Aviation	Marine
Dispatch operations	Extensive flight-control operations conducted by large commercial air carriers, including preflight planning and coordination with FAA air traffic control system, as well as in-flight routing, meteorological, and emergency support; flight-control services for small air carriers vary by operating company.	Local harbor dispatch services operated by some pilot associations and tug companies; availability and scale vary by organization and operational need. A few large inland towing companies operate computer or cellular phone communications networks to facilitate company operations.

Sources: Ives et al., 1992; Nolan, 1990; see also CCG, 1992; Glansdorp, 1987; Illman, 1993; Knott, 1989; Maio et al., 1991; Mizuki et al., 1989; Polderman et al., 1990; Young, 1994.

- the lack of familiarity of the master and bridge team with the handling of port-safety situations in the United States; and
- limited capability for effective discussion of decisions, actions and support needed by the pilot, local Coast Guard officials, or other port and public safety officials, particularly where language difficulties are present.

Interventions by a VTS also are limited by the state of technical development in vessel operations and personnel preparations for response. In commercial aviation, there are rigid specifications for construction, operation, and maintenance of aircraft, and for the training of flight crews (FAA, 1991; Federal Register, 1990; Guest, 1992a; Longridge, undated). The VTS intervention potential is constrained by variable technical capabilities and professional qualifications on ships and in the vessel traffic center (Chapters 1, 2, 3, and 6). An expanded VTS intervention role would necessitate concurrent improvements in vessels (particularly with regard to communications, positioning, and steering equipment); traffic center equipment; operational protocols; and the training of masters, bridge teams, pilots, and VTS watchstanders (Ives et al., 1992; Young, 1994).

Organizational structure and management practices described in Table 5-1 and Appendix H contribute significantly to the success of air traffic control. In contrast, the marine navigation and piloting system lacks strong organizational structure (Chapter 1). Furthermore, in aviation, there are a relatively small number of scheduled air carriers compared with the number of shipping companies. Air carrier fleets consist of many planes, whereas a large number of shipping and management companies typically operate only a small number of ships. Over 95 percent of commercial aviation landings and takeoffs involve U.S. aircraft. This means that the aircraft, operator qualifications, and operator performance are under direct U.S. jurisdiction. In contrast, about 95 percent of vessels engaged in foreign trade with U.S. ports are foreign-flag ships and are thus not under direct U.S. jurisdiction with respect to operator qualifications and only to some extent with respect to marine safety inspections. Also, the strong commitment to professional development and investment in training and training facilities by major air carriers is generally not paralleled in shipping. All of these factors distinguish these two transportation sectors from each other and affect the potential application of air traffic control concepts and procedures to the marine navigation and piloting system.

MARINE ALTERNATIVES TO THE AVIATION MODEL

Overview

As the preceding discussion indicates, many of the factors that make systemwide control feasible in the aviation environment are similar to those in the marine operating environment, but the levels of sophistication and application are different. There are also significant differences that affect vessel maneuverability (see Chapters 1 and 4). Although sophisticated marine navigation techniques and equipment have been applied to permit adherence to precise paths under select conditions (Chapter 6), implementing an identical control system for marine traffic is not feasible given the present state of navigation and piloting practices. Dramatic, universal changes would be required in navigational capability and operating concepts and practices, especially with regard to integrated system operation and professional development. Such changes would be international in dimension and would require international action to implement. While there is growing interest in strengthening marine traffic regulation, and some unilateral action has been taken, support for more formal control measures is uncertain (OSIR, 1993b; Ives et al., 1992; Young, 1994). Yet, it may be possible to adapt the organizational structure of the airspace system to the marine sector to begin the transition to a coupled infrastructure (Grey and Krop, 1979). It may also be possible to apply other control measures to achieve similar results.

Three options merit consideration:

- continuation and expansion of VTS systems into more ports as an information-based navigation aid;
- expansion and adaptation of the existing VTS system into a marine traffic regulation network (leaving pilots aboard ships) following the air traffic control concept; and
- shore-based direction of vessel maneuvering by shore-based marine pilots

in consultation with colleagues on board each vessel, or alternatively, control of individual vessels or select categories of vessels from a shore station (typically a VTS), through or in a manner replicating shore-based pilotage.

These options are described later in this chapter. Before introducing these concepts, however, the general nature of VTS systems is described, as is the VTS concept fundamental to each alternative. The following section outlines the VTS role, locations, and operating concepts worldwide.

Existing VTS Systems

VTS Programs and Objectives

Vessel traffic services are interactive, shore-based *communications* systems, usually augmented with surveillance equipment (principally radar) for acquisition of position and traffic flow data, that provide information and navigation support services to improve navigation safety and traffic efficiency (CCG, 1991b, 1992; Cutland et al., 1988; Herberger et al., 1991; IMO, 1985a; Ives et al., 1992; Koburger, 1982, 1986; Maio et al., 1991; Mizuki et al., 1989; Young, 1994). What a VTS could or should do is a subject of serious debate internationally. A useful VTS definition was developed for the Commission of the European Communities' examination of marine traffic and its safety (referred to as the COST 301 study) to make the *action* component of VTS explicit (Cutland et al., 1988; see also Hofstee, 1990a; IMO, 1985a):

> A VTS is any service, implemented by a competent authority, which interacts directly with the traffic and in response to that traffic in real-time in order to improve safety and efficiency of traffic and to preserve the integrity of the environment.

Because the term "competent authority" was not specifically defined by IMO and the International Association of Lighthouse Authorities (IALA), a common practice has been to apply the term "VTS" to systems meeting the other elements of the VTS definition. However, at the IMO level, the term is generally understood to apply to nationally recognized governing authorities, reflecting the organization's role and membership. Further, a new VTS definition proposed by IALA to IMO, if accepted, will distinguish between a VTS and a ship reporting system (Bell, 1992; G. Kop, IALA VTS Committee, personal communication, August 9, 1993, and September 23, 1993). As used in the present report, the term VTS applies to systems that meet the IMO definition and that are operated or sanctioned by nationally recognized governing authorities. The term "VTS-like systems" applies to systems that are not sanctioned by nationally recognized governing authorities, although such systems may function in like manner to a VTS, as described in this chapter.

The present report defines VTS functions as consisting of five more or less progressive categories of activities or services. These categories are as follows:

- general information services (such as collection and dissemination of vessel pre-movement information and regional weather reports);
- navigation advisory services (specific navigation information and advice);
- traffic direction/management (time-space management);
- shore-based pilotage (vessel-specific maneuvering orders); and
- traffic control (systemwide directed maneuvering).

Collectively, all five functions or services would constitute a generic model of a full-mission, comprehensive system for regulation of marine traffic. Depending on its form, a VTS can be far more than simply a service to its users.

In practice, a VTS may provide one or a combination of the first three services and functions. Some of these services are provided to all categories of vessels, while others may be vessel- or scenario-dependent. Directed maneuvering is not practiced except where shore-based pilotage services are offered through VTS facilities or, on an ad hoc basis, in extremely unusual circumstances or operating conditions or emergency conditions where certain vessel movements may become necessary (Herberger et al., 1991; Ives et al., 1992). Systematic control of all traffic is not practiced beyond coordinating queues (at locks, for example).

Coast Guard VTS operations are limited to the first three elements by agency policy. Also, while VTS-collected data often are shared with marine exchanges, the Coast Guard does not systematically collect or disseminate vessel pre-movement information specifically to facilitate port operations. Although the agency has considerable enabling authority to affect the movement of waterway traffic (traffic management authority is derived from the Ports and Waterways Safety Act of 1972 as amended), management of vessel traffic is applied sparingly. Specific maneuvering orders or instructions are given only in emergency or unusual situations. Although the enabling authority for intervention in these circumstances normally resides with the COTP, such action sometimes requires immediate decision-making in the VTC and on board the affected vessels in order to be timely enough to permit effective response by the person piloting the vessels. In exceptional situations, intervention is sometimes taken without prior consultation between a VTS and the COTP following the operating policies of the COTP and the local VTS director. Over the past several decades, there have been a small number of extremely urgent situations in which a VTS watch has intervened under the operating policies of the local VTS director without specific COTP guidance, the questions of specific authority notwithstanding. Such intervention in the interests of safety, when attempted, was usually in the form of highly specific information intended to influence onboard decision-making by eliciting a specific response. In a few situations, maneuvering instructions were provided. For example, there have been several occasions in which the Puget

Sound VTS intervened to provide maneuvering instructions to assist in pilot boarding after a foreign-flag vessel missed the Port Angeles, Washington, pilot boarding area and was standing into danger (Ives et al., 1992; Young, 1992, 1994).

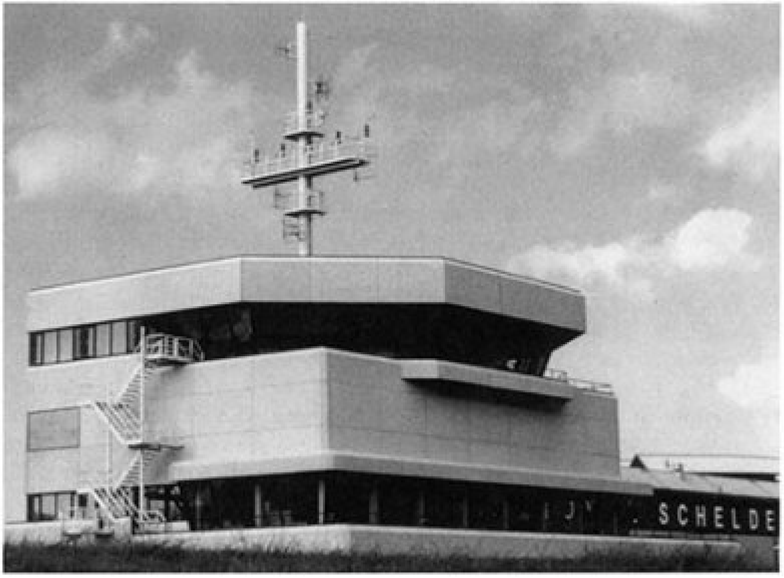
VTS Effectiveness

An acceptable analytical method has yet to be developed for fully measuring the effectiveness of VTS systems relative to all the factors that affect operational risk. Further, VTS performance data from which effectiveness might be assessed are limited. Nevertheless, major port needs and VTS studies, accident investigations, and limited near-miss documentation demonstrate that substantial benefits can be achieved through VTS operations (CCG, 1978, 1984, 1988, 1990, 1991c; EC, 1987; Maio et al., 1991; Quon et al., 1992; USCG, 1973, 1988b,c; Young, 1992, 1994). Substantial investments have been made in VTS in the interests of economic efficiency, to secure competitive advantage among ports (Rotterdam vs. Antwerp, for example), to improve safety, and for environmental protection. VTS investments are especially large where port operations are major contributors to local, regional, and national economies, as in Western Europe (Herberger et al., 1991; Mizuki et al., 1989).

In Europe, VTS was developed initially on a port-by-port basis as a means to improve safety and port efficiency; the extent of VTS installations depended on available port funding. To obtain support from port executives, development of a VTS had to be justified either in terms of statutory need or direct benefits over cost insofar as benefits could be determined (I. M. H. Slater, personal communication, Thames Navigation Service, July 27, 1993). Now, however, the perceived need for a businesslike approach to traffic management, safety, efficiency, and public and environmental safety is strong enough to underwrite support for the systems (Herberger et al., 1991; Nölke, 1988). Even though the payback of VTS is uncertain, some major ports engaged in fierce regional competition consider investments in VTS essential to attain the maximum level of efficiency consistent with safety (Herberger et al., 1991).

The advent of statutory requirements for reporting vessel movement data established VTS as a central information node. Information that is acquired can be recirculated by the VTS to shipping agents, facility operators, and others for use in improving port efficiency. This is done, for example, by the Port of London Authority on a paid subscription basis using modern electronic data transmission networks. The port authority uses the revenues that are generated to support VTS operations and improvements (I. M. H. Slater, personal communication, July 27, 1993; Slater, 1993).

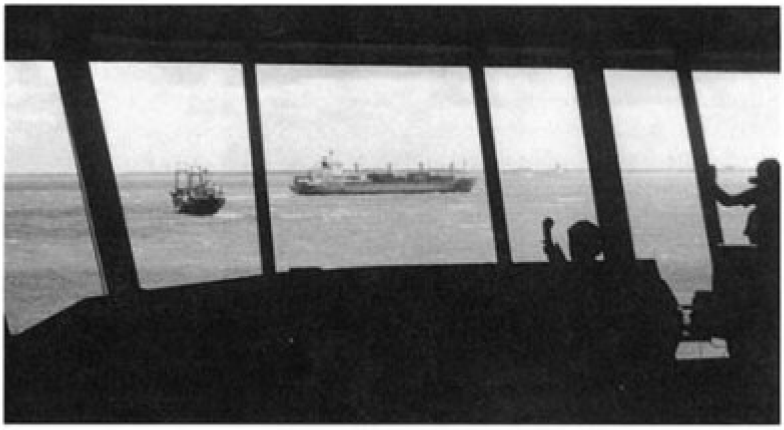
Vessel traffic management in major European ports has evolved to where widely disseminated "movement forecasts" are produced routinely based on information provided by agents, owners, and berth operators. In practice, these forecasts tend to become "daily orders" for traffic movement. The forecasts range from collections of random arrival and departure times to integrated movement programs taking into account waterway physical limitations, berth availability, priority of movement, potential congestion points, and other factors (I. M. H. Slater, personal communication, July 27, 1993).



Scheldt Coordination Center, a modern vessel traffic center located at Flushing (Vlissingen), the Netherlands. The River Scheldt VTS network conducts vessel traffic service operations for the River Scheldt, bordering coastlines, the port of Flushing, and for Belgian ports including Antwerp. (Wayne Young, *Marine Board*)

In the United States and Canada, installation of VTS is motivated primarily by safety objectives (CCG, 1984, 1988, 1991c; Maio et al., 1991; USCG, 1987). Economic benefits to operating companies, port authorities, and shippers are ancillary considerations in the government-operated systems. However, economic considerations (in addition to marine safety) are important concerns for some privately operated VTS or VTS-like systems, such as those in the ports of Long Beach and Los Angeles (Ives et al., 1992).

Environmental objectives have been increasingly important factors in decisions to establish and upgrade VTS facilities. Measures employed by VTS systems to satisfy environmental concerns include speed limits as well as management of time and space to prevent meeting and overtaking situations. The measures employed and their emphasis depend on many variables, including locality, operating or governing authority, enabling authorities, risk, port operations infrastructure, and VTS capabilities.



Visual overlook of the pilot boarding area from Scheldt Coordination Center supplements electronic surveillance of traffic activity in the convergence zone. (Wayne Young, *Marine Board*)

In the United States, there is no overall national direction and coordination for the development of VTS and VTS-like systems. Past development of VTS concepts and operating procedures occurred with little thought to standardization or commonality of purpose, except to some degree for Coast Guard-operated VTS systems where a level of uniformity was achieved through centralized program review and management (Ives et al., 1992). The Coast Guard's current VTS 2000 long-term acquisition program for 23 VTS installations nationwide and the operational requirements embedded in acquisition documents are directed only toward Coast Guard-operated systems (GAO, 1993b; Maio et al., 1991; USCG, 1993e, 1994). Although many members of the marine community had an opportunity to contribute to the *Port Needs Study*, the opportunity for public participation in developing or supporting the forthcoming VTS 2000 operational concept is more limited because of the nature of the federal acquisition process. However, the Coast Guard included several experts from the marine community, including a marine pilot, in the concept development team.

VTS Operations

Where there is no VTS, communications and decision-making in port areas tend to be highly segmented and vessel-specific. Transit information often is broadcast "in the blind" with no intended target. Vessels with a need for the information may or may not overhear the transmission. Vessel traffic services, in effect if not by design, lay a decision-making framework over the service area, using modern technology to link and improve decision-making aboard participating vessels. A VTS establishes a domain in which communications are conducted; reporting formats, content, and times are established; and use of circuit discipline in transmissions on prescribed frequencies is encouraged or enforced. Such developments suggest at least the possibility of vastly improved marine safety performance. This potential is reduced somewhat by limitations in existing operating practices and technologies for vessel–VTS interactions, particularly the reliance on voice radio communications and continuous monitoring as the primary means for traffic data transfer (see Box 5-2; Chapter 6; Young, 1992, 1994).

It is important to note that, as new operating conditions are established, old practices are altered or replaced. Such changes can enhance or degrade system performance, depending on how they are formed and implemented (NRC, 1990b). For example, after the Coast Guard-operated VTS in the Port of New York and New Jersey was shut down in 1988, mariners who had grown dependent on the disciplined information flow from the VTS had to return to informal, less precise traditional methods for broadcasting information about their transits (Ives et al., 1992; Young, 1994).

The Marine Community's VTS Advisory Role

Expertise from throughout the marine community has been used to guide constructive changes in marine traffic regulation. Such advice has been provided concerning the development and refinement of VTS operational concepts and the general monitoring of VTS performance. For example, in some U.S. ports, such as the Port of New York and New Jersey, New Orleans, and Houston, public advisory committees chartered by the DOT and administered by the Coast Guard provide advice on traffic management and harbor safety to local Coast Guard officials. In some other ports, including the Port of New York and New Jersey, and the ports of Los Angeles and Long Beach, locally or regionally sponsored organizations work toward similar objectives. In still other ports, such advice is obtained through established working relationships between Coast Guard regulators and those regulated.

Some foreign ports employ similar formal advisory committees to improve communications, planning, and performance of VTS systems. For example, one forum for discussing VTS matters is the Thames Marine Consultative Committee, which consists of port authority officers and representatives of user groups, lighthouse authorities, the Department of Transport (United Kingdom), marine pilots, shipowners, shipping agents, and others (I. M. H. Slater, personal communication, July 27, 1993).

BOX 5-2 VTS-USER INTERACTIONS

Although electronic data transmission is feasible, VTS systems in the United States and worldwide typically depend on data acquisition, processing, interpretation, and transmission by shore-based VTS operators. VTS operations are heavily dependent on voice radio communications, an inefficient and error-inducing medium for data transmission (Ives et al., 1991; S. Martin, 1992; USCG, 1988a,b,c; Young, 1992, 1994). There is also heavy reliance on the monitoring of transmissions made by the VTS and by VTS participants in order for each participating vessel to obtain a complete understanding of the overall traffic situation. Thus, VTS attempts to reduce or replace traffic assessments by the mariner based on incomplete information with the VTS watchstander's interpretation of what information should be communicated to the vessel and the timing of the transmission. The master or whoever is piloting the vessel then must determine the implications of this information for their immediate maneuvering situation and the vessel's overall passage. VTS interpretations of information needs may or may not be based on protocols developed in consultation with VTS-users, depending upon policies of the VTS operating authority, working relationships between a VTS and its users, the availability of a marine advisory committee or consultative organization, and the leadership exercised by the VTS director in working with clientele. The VTS also can serve as a safety check in the event that the traffic or maneuvering situation conveyed by the VTS is misinterpreted or misunderstood by whoever is piloting the vessel. Situations of this type are detected through surveillance, often in the form of monitored bridge-to-bridge communications. Sometimes, VTS communications are sectorized to reduce information loading and radio interference. Nevertheless, the reliance on voice radio communications combined with difficult operating conditions can result in information overload. Interest is growing slowly in improving the collection, processing, interpretation, and use of essential navigational information; of particular interest are means for providing essential information in a form conveniently used aboard the vessel (Herberger et al., 1991; Ives et al., 1992; Young, 1992, 1994).

IMPROVING WATERWAYS MANAGEMENT

Port-by-Port Expansion of VTS

Additional VTS systems could be installed in the United States, but a variety of issues would need to be resolved first. Federal resources are limited. There are concerns about the Coast Guard's staffing practices; its capabilities to build and maintain the necessary professional expertise; and, in the past, its lack of long-term commitment to operating VTS systems. There is also concern about the national commitment for continuing operation of VTS systems (GAO, 1988;

Ives et al., 1992). Further, the VTS potential to reduce operational risk may be such that installation of a full-mission VTS in some ports would not be cost-effective, although potential improvements in economic efficiency might justify such an investment. Therefore, it is useful to consider alternatives to federally operated systems and to a full-mission VTS system. Regardless of the operating authority, VTS systems require standards and consistency in operations and procedures and compatibility in equipment, especially when these standards and consistency of their application involve vessels participating in the VTS. Otherwise, the overall effectiveness of a system is reduced, particularly for users from outside the local port region.

The General Accounting Office, in a 1975 review of the Coast Guard VTS program, recommended that the agency provide limited-scale VTS systems in many ports rather than full-mission systems in a few ports (GAO, 1975). The Coast Guard instead chose full-mission systems to provide more complete navigation support in ports that were served. With the limitations of the technologies prevailing in VTS operations (voice radio communications and radar), extensive data collection and processing is required of VTS operators. Now, however, VTS technology has advanced to the point where automated systems can greatly improve the efficiency of data collection, presentation, and transfer, permitting human operators to focus on data interpretation and use. It is also technologically possible to provide electronic position monitoring for ports with low traffic volumes and reduced information-sharing needs through means other than voice radio or radar (see Chapter 6). This development could permit the establishment of VTS systems with modest human-resource requirements. Such an approach would require expert understanding of specific navigation and piloting needs within targeted port and waterway systems to ensure that a mini-system would satisfy these needs.

Cost reductions might make it possible for local sponsors to operate small-scale VTS or VTS-like systems. If the potential major benefits of a VTS could be attributed to information sharing rather than intervention, for example, then a modest installation with perhaps one or two operators on watch, depending on workload, might be sufficient and within the resource capabilities of local sponsors. However, if interventions were an operating objective, requirements for professional expertise and supporting equipment would be substantially greater, and exposure to liability would increase as well. The overall liability of VTS facility operators (and watch personnel) and whether limits on liability should be instituted are implementation issues that would require further assessment.

Measures to cover costs of full-mission systems could include federally or state-funded operation, public subsidies of private operations, increased port charges, imposition of user fees, or perhaps allocation of customs fees collected as duties on international marine cargoes moved through U.S. ports. It also may be possible to develop cooperatively operated systems. This could be accomplished through joint funding, joint staffing, or co-location of VTS systems with organizations providing essential functions (such as the COTP, pilot dispatch office, marine exchange, or port authority operations offices). Such approaches could facilitate information sharing and professional consultation. However, interorganizational relationships would require careful examination, and appropriate protocols would need to be established. For example, typical COTP law enforcement, port security, and marine pollution response activities might require some degree of confidentiality, thereby imposing constraints on participants in a jointly operated or co-located system. Cost sharing also would need to be addressed.

Whether VTS or VTS-like systems should be run privately or by a federal agency is unresolved. Both forms exist in the United States; however, only VTS systems operated by the Coast Guard and the Saint Lawrence Seaway Development Corporation are addressed in the 1992 Federal Radionavigation Plan (DOT and DOD, 1993). The plan is silent with regard to non-federal VTS or VTS-like operations or marine traffic regulation conducted by other federal agencies, such as that performed by the Army Corps of Engineers for transits of the Cape Cod Canal (USACE, 1980).

The Coast Guard has a national infrastructure for administering a nationwide program as well as experience in operating VTS, but the agency lacks the resources for a major expansion. Additional federal funding would have to be provided (GAO, 1993b,c), or resources reallocated from other programs. Further, national professional development standards have not been established for VTS watchstanders nor is national-level generic training available (Ives et al., 1992). Although international VTS operating guidelines are available (IALA, 1990; IMO, 1985a; F. Weeks, 1992), private VTS and VTS-like installations are not required by the Coast Guard to follow such standards. There are no accreditation or approval programs for private VTS or VTS-like operations, no certification programs or licensing requirements for individuals performing VTS functions, and no official oversight (Ives et al., 1992). Whether private operations could assume proactive, full-mission VTS operations is unclear.

At the port level, organizations such as marine exchanges and pilot associations have demonstrated the capability to operate small-scale VTS or VTS-like systems. However, most pilot associations are not organized to provide VTS services, although some may have reserve capacity that could be applied to this purpose. Further, not all individuals are well suited to coordinate a systemwide VTS operation or serve as a VTS watchstander.[3]

Whether Coast Guard personnel are sufficient in number to provide manning for a major VTS expansion in the near term is not certain. However, staffing needs could be reduced by the adoption of technology that would reduce the

[3] A watchstander position in a full-mission VTS system imparts less professional stature (and financial compensation) than does the traditional marine pilot's position, but the comparison is not direct because watchstanding typically requires different technical expertise.

need for extensive manual collection and processing of traffic information. In the long-term, technology that permits electronic rather than voice radio transmission of general traffic information could potentially reduce manning requirements while also reducing the potential for human error. Increased use of civilian employees as watchstanders also may be feasible at some locations.

Cape Henry pilot tower operated jointly by the Association of Maryland Pilots and the Virginia Pilots as a pilot dispatch and small-scale, information-oriented VTS system. (William F. X. Band, *Association of Maryland Pilots*)

In assessing requirements for large-scale VTS operations, a long-term staffing commitment by the entity that operates or supports operations is a major issue. Manpower needs include provisions for communicating with foreign-flag ships prior to boarding a marine pilot, an important factor in ensuring that ships make it safely into the pilot boarding area. Stress and burnout also merit attention if personnel assignments are extended to VTS watch duties. These factors typically are not addressed in comparisons between vessel and VTS operations and professional requirements.

Pilot dispatcher, Cape Henry pilot tower. (William F. X. Band, *Association of Maryland Pilots*)

Adapting the Aviation Model to Marine Transportation

Another option is to develop a marine traffic regulation system that mirrors the air traffic control system in concept if not in function, using and expanding existing VTS systems as the centerpiece. Many segments of a nationwide system already exist. Coast Guard field offices (which already have access and contribute to the agency's marine safety information system) might provide an organizational framework that could link vessel movement information. Vessel movements would not necessarily have to be monitored in real-time at all locations, depending on factors such as traffic volume. Existing VTS systems could provide the structure, rules, and procedures for coordinated decision-making throughout the VTS service area. The system also could be linked with state and local pilot associations, which are not organized at present to provide national services. A linked system could provide for improvements in pre-arrival reports, vessel performance tracking, and near-miss reporting, while also obligating vessels to use standard protocols and procedures.

Because existing facilities would be used, such a system could be implemented relatively quickly and at modest cost. However, system changes would also result in modified operating behavior among system users. Therefore, changes of this magnitude must not be approached casually. A long-term commitment to system operation and maintenance from the Coast Guard, the DOT, and the Congress would be essential to system continuity and effectiveness. Conceivably, such a system also could provide real-time vessel performance information, which could be developed into a national reporting system for near misses. This application would help overcome current data limitations for identification and analysis of safety performance of individual vessels, operating companies, and the navigation and piloting system.

An alternative would be to establish more VTS systems without linking them together. This option could lead to improved safety within the ports and waterways served, but it would not provide the added value possible by linking the systems together on a broader scale.

A major obstacle to creating a marine traffic regulation network is the fact that, nationally and internationally, VTS systems don't cover all ports. Moreover, even where VTS systems are present, they differ in operating procedures and levels of service. These variables, and indeed the very existence of a VTS, add to the range of knowledge and expertise required on vessel bridges and in pilot houses for safe navigation. While local operators appear able to adjust to a local VTS, individuals from other regions have more difficulty learning system practices, particularly where trade routes expose bridge team personnel to multiple VTS systems or where vessels call on the same ports infrequently. These problems are compounded by the great diversity in manning and operating practices associated with the merchant vessels that trade with the United States. All these factors suggest a need for VTS procedural standardization and for marine pilots to provide local procedural knowledge in addition to navigation and ship-handling knowledge and skills. VTS standards and guidelines published by IMO and IALA could serve as a foundation for developing national VTS standards. However, some local flexibility would likely be necessary to accommodate unique local operating conditions.

Shore-based Pilotage

Vessel maneuvering can be directed and controlled by individuals not aboard the vessel to some extent. This practice occurs on a limited basis in the form of shore-based pilotage (also called "assisted passage" transits or "remote pilotage"). Those providing shore-based pilotage today do not purport to con a vessel into or out of port. Rather, the objective is to provide information to a vessel's master or pilot (if aboard) that will supplement available bridge team information and ensure the safest possible passage. Information that is typically provided includes positional information, traffic data, navigation information on the course to make good (that is, the course adjusted to compensate for physical forces needed to adhere to a trackline), vectors and distances, identifiers of navigation marks, and other information normally used by a pilot. Directed maneuvering by shore-based personnel analogous to aviation practice is considered beyond the capabilities of existing navigation equipment. Nevertheless, individuals and organizations providing shore-based pilotage expect that the person piloting the vessel will adhere to whatever instructions are provided in order to receive this service (Herberger et al., 1991; Ives et al., 1992; I. M. H. Slater, 1993, personal communication, July 27, 1991).

Shore-based pilotage generally is provided on an exception basis, such as when it is needed to guide vessels to a position where a pilot can board during adverse weather conditions. This form of service is provided by marine pilots in a few ports (including Rotterdam and Vlissingen [Western Scheldt River approaches], the Netherlands, and Kent, England [Thames River estuary]) under very select criteria (Herberger et al., 1991). Conceptually, shore-based pilotage also could be used to ensure that vessels unable to enter a port remain out of dangerous waters while awaiting more favorable conditions.

Marine pilots providing shore-based pilotage usually use VTS communications and informational resources, but the pilotage is usually not formally provided by the VTS (Herberger et al., 1991; Ives et al., 1992). An exception is the Port of London, where pilot and VTS services are both provided by the Thames Navigation Service (I. M. H. Slater, personal communication, June 29, 1993). Shore-based pilotage normally is limited to small and moderately sized vessels, which generally are more maneuverable than, for example, large tankers.

Some VTS systems provide limited and selective navigation support to marine pilots and masters similar to that provided by a member of the bridge team dedicated to providing navigation support. This is not shore-based pilotage in the strictest sense. Typically, navigation support services aid in positioning in anchorages. Services of this form are provided to marine pilots by Jacobsen Pilot Service in Long Beach Harbor, by the Vancouver VTS Center in Canada, and by VTS New York, which also has assisted tugmasters in positioning barges (Ives et al., 1992). Emergency pilotage-like services also are sometimes provided. In one worst-case scenario in the Thames estuary during the 1970s, the assigned marine pilot died during the vessel's inbound passage. A watchstander at the London VTS, under the supervision of an experienced VTS controller, effectively directed the foreign-flag vessel (despite severe language difficulties) into an anchorage to await arrival of a replacement pilot (Herberger et al., 1991).

With the exception of the Puget Sound VTS, U.S. Coast Guard-operated VTS systems do not provide maneuvering orders. Puget Sound VTS has done so on a few occasions, usually involving a foreign-flag ship that missed the Port Angeles pilot station and was standing in dangerous waters of the eastern Straits of Juan de Fuca. The maneuvering instructions were designed to move the ship out of danger and to permit boarding of a marine pilot. As with navigation support, such emergency actions mirror shore-based pilotage but do not reflect the full meaning of the term. For one thing, such interventions are based on policies and procedures established by the unit commanding officer (VTS director) and the Coast Guard's tradition of emergency response, rather than on specific policy. Further, although interventions are sometimes feasible using only communications systems, the potential for error is increased in the absence of appropriate surveillance coverage.

Establishing a national, comprehensive system of shore-based pilotage would be no simple matter. There are philosophical, organizational, technical, staffing, and liability issues. The national and international marine communities have not supported issuance of maneuvering orders to a vessel from a shore-based facility, except where this is a noncompulsory service offered by marine pilots. Even if a broader shore-based pilotage system were mandated for some or all ports, the implementation issues would be formidable (Herberger et al., 1991; Ives et al., 1992). To achieve maneuvering results comparable to those of an accomplished marine pilot, the controller would have to acquire, filter, process, and integrate dynamic and complex information affecting each ship and then translate it into positioning, continuous maneuvering control, and trajectory maintenance. It would be difficult, if not impossible, for VTS watchstanders who are not already skilled in marine navigation and piloting to acquire sufficient skills to undertake such a role. (In contrast, an air traffic controller is not asked to fly the planes or to integrate the many cues that must be considered in deciding something as simple as when and where to turn.) Even if the VTS were able to acquire the necessary data, the information still would have to be integrated, decisions made, orders fed back to the vessel under control, and timely and correct action taken by the vessel operator.

Because navigation and shiphandling require constant attention in piloting waters and appear to demand substantial analysis and interpretation of all available cues, it is not clear that more than one vessel could be controlled at once by a single individual ashore. Implementation of this option, beyond highly selective scenarios using existing pilotage infrastructures, could raise the costs and professional requirements for providing these services. Liability issues also would need to be resolved. Decisions would have to be made regarding personal or corporate liability for faulty provision of VTS service (or perhaps VTS inaction) leading to a casualty with resulting damages to vessels, cargoes, or the environment or with loss of life.

If policy makers insisted on developing a marine navigation and piloting system using shore-based pilotage, and if the complexities of vessel maneuvering required that controllers had the skills associated with marine pilots, then building the requisite work force would present additional challenges. The existing marine infrastructure is not organized to train sufficient numbers of individuals with pilot-like expertise.

IMPLEMENTING MORE RIGOROUS MARINE TRAFFIC REGULATION

Establishment of more rigorous waterways management through marine traffic regulation of any form would not be easy. Considerable cooperation would be needed among the Coast Guard, the marine community, and the U.S. Army Corps of Engineers (with respect to its federal navigation projects, to effectively respond to the many issues identified in this chapter. Any expansion in VTS systems would require assurance of broad-based confidence in their effective manning, operation, and maintenance. Clearly, the Coast Guard has developed considerable experience in operating VTS systems at selected locations, and considerable local support for them has evolved (Ives et al., 1992). Yet, there is scant quantifiable data to prove VTS effectiveness in improving marine safety (Ives et al., 1992; Young, 1992). Additional doubts exist in the marine community concerning the agency's past history of wavering in its commitment to VTS (Ives et al., 1992). Given these concerns, agency involvement in regulating private VTS or VTS-like operations to ensure consistency and integrity—emulating the aviation model—would stimulate considerable debate. All the same, safe-guarding ports and waterways is a Coast Guard statutory responsibility under Title 14 of the U.S. Code.

Expanded marine traffic regulation could benefit from increased consultative relationships between the Coast Guard and the marine community at the national and port levels. Such arrangements could enable the Coast Guard to gain access to the specialized expertise needed to guide planning and decision-making and to build mariner and industry "ownership" in whatever approaches are selected. Expansion of marine traffic regulation beyond basic VTS concepts would entail a major change in national policy and direction that would greatly exceed the resources presently applied to this purpose.

An alternative means for ensuring the availability of essential expertise, strengthening professional credibility, and building mariner and industry "ownership" of more rigorous marine traffic regulation would be to form a national commission to guide improvements. The commission could set criteria for the use of VTS and qualifications for organizations and personnel that operate them. If the membership of such a commission included representatives from the marine community, the public, and the Coast Guard, this balance would provide the expertise necessary to guide implementation while also establishing broad-based professional credibility. In the concept envisioned here, the Coast Guard would be responsible for regulatory oversight, administration, and interagency coordination to ensure adherence to and implementation of these standards; these activities would draw on the agency's existing enabling authorities, administrative capabilities, and national port-level infrastructure. Also envisioned is Coast Guard coordination with the Saint Lawrence Seaway Development Corporation and the Army Corps of Engineers to promote consistent application of national VTS standards in marine traffic regulation activities conducted by these organizations.

6

Navigation and Piloting Technology

SUMMARY

A broad range of vessel- and shore-based technologies are emerging that have considerable potential for improving navigation safety. The effective application of high-technology in operations and professional development programs offers a substantial means to significantly reduce risk in the near term. International technical and performance standards and criteria, and corresponding national standards and criteria are needed to guide the systematic introduction of new navigation technologies with capabilities and configurations that are well designed to enhance navigation safety. Technology is an important component of an overall approach for solving safety issues confronting marine transportation. To achieve the full potential of advanced technology for improving safety, systemic factors will need to be comprehensively addressed including (1) operator qualifications and training, (2) manning, (3) pilotage, (4) systems maintenance, (5) regional variations in port and waterway operating environments, (6) economics, and (7) institutional policies.

Successful application and effective use of new and innovative technologies require validation of the technologies, changes in operational procedures, and operator training. These efforts are necessary not only to ensure suitability and reliability of complex and integrated systems but also to demonstrate the practical value of these systems to mariners. Validation methods for navigation technologies that rely on software are not fully developed; there are few proven methodologies that offset the need for extensive field trials in the full range of operating conditions in which these technologies will be applied. Reliability as

sessment techniques using statistical models are not mature for determining system faults in software-dependent systems. Further, although the capability to tailor visual presentations of navigation data can be a powerful tool, it also has the potential to increase risk. For example, important navigation information could be screened out of the display if system designers or users lacked full appreciation of information needs across an entire transit or if there were no safeguards in design or operating practices to prevent this from happening.

Apart from being time-consuming, the traditional method of validating technology through trial and error during actual operations can expose a vessel to danger. Moreover, this method lacks adequate controls, monitoring, and evaluation regimes to ascertain technology reliability. At sea use of navigation technology does not prove system effectiveness for ports and waterways applications due to differences in operating conditions and operational requirements. Indeed, error-free performance of technical systems at sea can lead to premature confidence and trust in their capabilities for use in pilotage waters.

The ever-expanding variety of navigation technologies multiplies the demands on marine pilots, who ideally would be knowledgeable and skilled across the entire technological spectrum. Similar demands are placed on docking masters, especially those providing harbor pilotage services. Although marine pilots could not possibly become familiar with every technological permutation, their knowledge and skills are valuable resources that could be effectively applied in validating new navigation technologies.

As technology solves one set of problems, others may be created. A requirement for specific electronic precision navigation equipment may or may not achieve the intended results in actual operations, depending upon system capabilities, the operating conditions in which applied, and mariner acceptance of and proficiency in using the technology. Further, legal or regulatory mandates for a specific technology could constrain development of other electronic navigation systems and associated benefits; other navigation technologies, marine traffic regulation, or enhancement of pilot professional qualifications (perhaps through vessel- or area-specific training or shiphandling simulation) could prove to be better alternatives for improved safety in certain operating conditions. Historically, once in general application in commercial operations, technology rarely has been formally or scientifically assessed for effectiveness to establish a basis for refinements and further applications. Concern over creating new problems becomes more critical if technological advances have been dramatic enough to warrant new professional requirements for operators or if a technology precludes or inhibits human intervention to override automated systems, for example, when needed to overcome system malfunction.

The mariner's traditional conservative approach to change is understandable in view of concerns over the need to establish confidence in system performance for ports and waterways applications and the need for training in system operation. However, the desirability of reducing operational, economic, and en vironmental risks nevertheless argues for accelerated introduction, validation, acceptance, and prudent use of high-technology navigation systems.

INTRODUCTION

High-technology navigation systems have matured to the point where, if used wisely and adequately supported, they have the potential to enhance maritime safety and transit efficiency significantly. Satellite technology such as the Global Positioning System (GPS), for example, can provide continuous and very accurate position fixing that can support both navigation and operational scheduling. Advances in electronic charting and bridge automation can reduce the need for manual processing while facilitating the interpretation and optimal use of navigation information. The application of expert systems can offer support for decision-making and for overcoming human error. These and other advanced technologies could help masters, marine pilots, and ship's conning officers cope with a variety of long-standing navigation and piloting difficulties as well as certain factors that can affect visibility or maneuverability on large modern ships. These problems include impaired visibility from the bridge; large wind-catch areas; and the propensity to maintain momentum for long distances, particularly for loaded tankers.

The dual nature of navigation technology—great potential balanced by serious potential pitfalls—is emphasized throughout this chapter, which examines options for enhancing safety by improving technology. The committee views technology as a powerful means for improving safety, but not as a panacea for the safety dilemmas confronting the maritime industry. In the marine transportation sector, technology application is approached from different perspectives and driven by differing needs—economics, safety (operational, public, or environmental), assigned missions, or a combination of these. Sometimes these needs point to the same technological solution, but the relationship among them is not always obvious. Also not always obvious is the potential economic benefit of emerging technologies to operating companies.

The chapter outlines how mariners currently use technology and explores possibilities for further technology development. Options for incremental and strategic improvements are presented. The chapter concludes with an overview of how navigation technology is adopted in the maritime world and the implications of this process. Short descriptions of navigation and piloting equipment and the traditional ship bridge design are provided in Appendix G.

SUMMARY OF IMPROVEMENT OPTIONS

The improvement options identified in this chapter are summarized in Table 6-1. Although not an exhaustive list, the summary provides the committee's estimate of the time frame in which improvements might be made in each area.

TABLE 6-1 Summary of Technology Improvement Options

Category/ Option	Immediate Action	Near-term Action	Long-term Action
PASSAGE PLANNING			
• Develop international standards for electronic charts	x		
• Develop international standards for electronic chart systems	x		
• Develop international standards for automated chart corrections	x		
• Require electronic charting systems to meet international standards		x	
• Provide electronic chart data bases by or through national hydrographic offices		x	
• Conduct more timely and complete hydrographic surveys		x	
• Develop automated systems for chart corrections		x	
• Provide accurate, timely reports on environmental conditions		x	
• Expand real-time environmental information systems			x
POSITION FIXING			
• Develop minimum international standards for Electronic Chart and Display Information Systems (ECDIS)	x		
• Indemnify from liability providers of electronic charts and manufacturers of electronic chart systems	x		
• Review and if necessary revise laws and regulations for bridge team operations	x		
• Retain paper charts as a backup for ECDIS		x	
• Improve accuracy of short range aids to navigation		x	
• Improve positioning of buoys and fixed aids		x	
• Expand distribution of racons and high-intensity lighted ranges		x	
• Develop and install electronic ranges for poor visibility conditions		x	
• Accelerate implementation of GPS and DGPS		x	
• Accelerate development of electronic charts		x	
• Accelerate schedule for harbor surveys		x	
• Increase attention to human factors aspects of ECDIS		x	
• Develop long-range plans for improving aids to navigation			x
• Review long-range plans for production of charts			x

Category/ Option	Immediate Action	Near-term Action	Long-term Action
COMMUNICATIONS			
• Aggressively enforce VHF radio regulations		x	
• Improve Vessel Traffic Service (VTS) communications procedures to reduce potential for human error		x	
• Implement more efficient data communication in VTS-user interactions		x	
• Improve radio circuit discipline, including institution of standardized vocabulary		x	
• Create additional VHF channels for commercial users			x
• Improve radio bandwidth efficiency			x
COLLISION AVOIDANCE AND SURVEILLANCE			
• Develop new Automatic Radar Plotting Aid (ARPA) functions and display capabilities		x	
• Review, revise international ARPA standards to permit use of alternative technologies for speed measurement		x	
• Standardize data outputs from integrated systems		x	
• Adapt low-light video and sound discrimination systems for marine use		x	
• Increase use of advanced technologies such as automated dependent surveillance (ADS) in VTS operations where feasible		x	
• Conduct comprehensive analysis of requirements for ADS data communications			x
• Accelerate research of efficient data communications systems			x
STEERING AND TRACK KEEPING			
• Improve autopilot algorithms for shallow-water maneuvering			x
• Allow use of high-performance autopilots in pilotage waters			x
• Establish legal equivalency of ECDIS for plotting			x

Category/ Option	Immediate Action	Near-term Action	Long-term Action
BRIDGE TEAM MANAGEMENT AND DECISION MAKING			
• Accelerate use of integrated navigation systems		x	
• Develop more complete standards for NEMA 0183		x	
• Develop standards for interfacing bridge equipment, engineering systems, and cargo/ballast systems		x	
• Develop international standards for alarms, displays, and controls used in Integrated Ship Control Systems (ISCS)		x	
• Develop rules for bridge configuration of ISCS		x	
• Redefine automated dependent surveillance (ADS) to develop a performance-based standard		x	
• Conduct research and development to improve ADS to simplify integration and reduce cost		x	
• Encourage development of portable communications and navigation systems (PCNS)		x	
• Develop piloting expert systems to support integrated bridge systems (IBS) and integrated ship control systems (ISCS)		x	
• Develop expert systems for complex, busy waterways		x	
• Conduct research and development to improve compatibility of expert systems with PCNS, IBS, and ISCS		x	
• Dedicated radio frequencies for marine electronic data transmission			x
• Develop efficient and standard data protocols			x
• Develop international standard for ADS			x
• Conduct risk assessments of integrated bridge operations and equipment			x
• Develop regulations allowing non-traditional bridge team			x
• Review and amend manning laws and regulations			x

Category/ Option	Immediate Action	Near-term Action	Long-term Action
WEATHER AND ENVIRONMENTAL MONITORING			
• Transmit PORTS data electronically for use with ECDIS		x	
• Improve hull stress sensors and methods for mounting them		x	
• Extend PORTS system to provide service to all major U.S. harbors			x
DOCKING EVOLUTIONS			
• Conduct research and development to hasten implementation of automated docking systems		x	
• Develop more-reliable winch-control systems		x	

IMPROVING NAVIGATION TECHNOLOGIES

A wide range of technological options for enhancing maritime safety was examined during the study. The analysis presented here is organized by navigation and piloting function. Within each functional classification, the current state of practice is outlined, and options are identified for immediate action, incremental improvement, and long-term development of technologies. For purposes of clarity, the options are *italicized* in the text.

Immediate action items are those needed to guide the application of emerging technologies. They deal principally with technical and performance objectives and standards. Incremental improvements were defined as those already under way or achievable in one to three years. Long-term development alternatives were those only now being proposed, those having an uncertain time horizon, or those requiring extensive international coordination or change to implement. Such strategies would be slow to produce effects but would have the benefit of ensuring that the diverse elements of the maritime community worked together and had time to accept any changes.

The functional classifications include:

- passage/route planning;
- position fixing;
- communications;
- collision avoidance and surveillance;
- steering and track keeping;
- bridge team management and decision-making;

- weather and environment monitoring; and
- docking evolutions.

The analysis assumes some basic knowledge about each technology. This background is provided in Appendix I, which defines each technology mentioned in this chapter and describes the traditional bridge setup, including placement of technologies. Several important off-ship technologies, including VTS systems and marine simulations used for waterway design and pilot training, are addressed in detail in Chapters 1, 3, and 5 and Appendix E.

Passage/Route Planning

Mariners plot their intended track line on a paper nautical chart showing waypoints for course and speed changes. The technologies used include traditional nautical charts; navigation publications such as the *Light List*; and where available, electronic charting systems.

Various technical and institutional factors constrain the full application of electronic charting technology. These include the lack of international performance standards (although these are under development), the unavailability of government-provided electronic charts or chart data, and the fact that the hydrographic data that are available for many pilotage waters are not as accurate as is the capability to determine precise positions using differential GPS (DGPS) and electronic charting systems. Further, the process of accumulating electronic data bases is slow and costly.

Choosing the Charting Medium

The choice of paper or electronic chart may be based on the relative advantages of the presentation format or the ease of use. (Paper and electronic charts also differ in legal status, an issue discussed later in this chapter.) Paper charts permit the user to see wide areas in sufficient detail to assist with voyage and route planning, and they can be folded and moved about the bridge to aid in visual orientation and identification of geographic features and aids to navigation. They also remain available for use if an electronic charting system fails to operate correctly or becomes disabled.

Whether all features of paper charts can be replaced by electronic charts has not been established (Gold, 1990a). Electronic charts, while capable of providing the same or greater detail as paper charts over wide areas, must either condense this information into a smaller display or present only sections of charts (scaling factors as they affect accuracy are discussed later in this section). On the other hand, precise navigation data and radar images can be integrated into an electronic presentation to provide real-time steering guidance and hazard-avoidance features. Additionally, software-driven, computer-aided features can be de signed to aid in data analysis and decision-making. For example, color coding could be generated to mark depth contours. The master, pilot, or watch officer can determine what hydrographic data are displayed to aid in their transit. Critical information needs vary from situation to situation. It is probably not necessary to display *all* information at *all* times. In fact, the most effective use of electronic chart display features appears to be selective display of information. However, an incomplete understanding of information needs for a transit or errors made in selecting what data are displayed could result in failure to display all key information needed at various locations along the vessel's route. What to display and when to display it are basic issues in determining whether Electronic Chart Display and Information Systems (ECDIS) can replace existing traditional equipment such as a separate radar console and paper charts. Empirical research is currently under way to assess which information in an ECDIS is most used, and which is most useful to the mariner (Smith, 1993).

These factors could complicate establishing use of electronic charts as legally acceptable replacements for paper charts for planning and conducting navigation. Performance criteria would need to address minimum display requirements for hydrographic data and ship parameters such as depth, breadth, and maneuvering characteristics. In any case, it would be important for the mariner to be aware of which data will be displayed automatically and to what extent this data can be controlled by the user.

Scaling Factors

The scale of electronic chart displays needs to be constrained to ensure that chart data are not depicted at larger-than-intended scales, because the level of charted detail and the accuracy change with the scale of the chart. In general, the larger the scale and the smaller the area display, the more accurate the feature based on field survey standards and the precision with which data can be presented. The standards for the horizontal accuracy of paper charts are based on the scale of the original field survey. Normally, the error budget for a chart is 0.8 mm at the scale of the survey. For a 1:50,000-scale chart, features and soundings are thus required to be accurate to 40 m; for a 1:10,000-scale chart, 8 m. The scaling constraint undoubtedly will lead to demands for new, large-scale, highly accurate hydrographic surveys, especially of harbors and harbor approaches (Donald Florwick, NOAA, personal communication, October 30, 1992). It also may be useful to have software switches that change the level of detail to correspond to the scale presented on the electronic chart visual display. Further, the hydrographic data need to be very accurate and reliable so that the mariner is not given a false sense of security, because the appearance of the high-technology display may be better than the data presented.

Thus, even as electronic charting systems can offer unique additional support for navigation functions other than voyage planning, they also have the potential to induce error through data screening features. Therefore, the federal agencies involved in development of standards for electronic charting systems are supporting the ECDIS concept. Only electronic charting systems that meet international performance standards including some minimal level of detail would carry the ECDIS designation and be considered to meet legal carriage requirements.

Accuracy of Nautical Charts

An electronic charting system, when combined with real-time position data conveys a convincing sense of reality. The visual presentation can be easily related to the maneuvering situation, facilitating the interpretation and application of displayed information. This capability appears to cause users familiar with system operation to believe the video display and to become increasingly reliant on it. Therefore, the information displayed needs to be as accurate as possible.

Although electronic charting systems offer real-time utilization and increased precision in position fixing, and rapid update capability, the available hydrographic data upon which these features rely are incomplete (Box 6-1). Thus, the hydrographic data bases for electronic charts will not be any more reliable (in general) than those for paper charts in the near-term, because the same survey data are used. Because the accuracy of the available data is generally less than the precision by which the data can be displayed by an electronic charting system, mariners must consider the limitations of the data when using these systems.

Another accuracy factor is that NOAA has a substantial backlog of reported chart discrepancies that have yet to be resolved. The agency is capable of conducting field investigations of only about 20 percent of reported discrepancies each year. NOAA, which produces 1,000 different nautical charts, had almost 2,000 request for new surveys as of August 1993, some dating back to 1984, and 400 to 500 new wrecks and obstructions are reported annually for the East and Gulf coasts alone (NRC, 1994).

NOAA plans to make users aware of the limitations of nautical paper charts by adding source diagrams, which will show the date, source, and scale of the survey data (Prahl, 1992). Knowledge of chart shortcomings will help users make informed decisions. But even greater demands will be placed on hydrographers by the nature of electronic displays. The development of digital hydrographic data bases is the most labor-intensive and costly step in making electronic charts available to the mariner. The International Maritime Organization's (IMO) ECDIS Provisional Performance Standards require that data bases be supplied by a national hydrographic office. However, electronic chart data bases must be developed on an international scale to provide complete coverage and updated regularly, and there needs to be consistency in units of measure;[1] the process involves digitizing paper charts and, ideally, conducting new hydrographic surveys using state-of-the-art technology to provide 100 percent bottom coverage in significant areas. The data formats and procedures to produce the data bases are in place, [2] but digitizing paper charts of U.S. waters alone is ex

BOX 6-1 ADEQUACY OF HYDROGRAPHIC SURVEY DATA

Nautical charts are prepared from the latest available hydrographic surveys, collected with the latest available technology. However, only a small portion of U.S. waters have been surveyed using the most advanced techniques. Many present charts for U.S. waters are based on lead-line surveys or depth profiling, technologies dating back 50 years or more. Over 60 percent of the soundings shown on nautical charts are based on lead-line surveys conducted prior to 1940. Lead-line surveys provide only spot soundings (a very limited sampling of the ocean bottom). More modern trackline surveys are limited to the track of the sounding vessel. All dangers to navigation may not be indicated on a sounding scheme even when used in conformance with established hydrographic standards. These technologies do not provide absolute determinations of the sea floor; rather, they provide statistical samples of the shape of the bottom. New multibeam sonar and laser technologies allow hydrographers to sound 100 percent of the sea floor, an important benefit in areas of heavy marine traffic. But few surveys have been done this way. Of the 3.5 million square miles of water area that are the responsibility of the National Oceanic and Atmospheric Administration (NOAA), only a small portion has 100 percent bottom coverage (Andreasen, 1992; Ganjon, 1990, 1991; Thomas W. Richards, NOAA, personal communication, April 30, 1993). The grounding of the *Queen Elizabeth 2* on an uncharted pinnacle in the vicinity of a charted reef, and breaching of her hull near Martha's Vineyard on August 7, 1992, vividly demonstrated the need for modern hydrographic surveys—and more prudent navigation (Dibenedetto and Cantwell, 1992; Manley, 1992; Marine Log, 1992; NTSB, 1993; USCG, 1993b). No hydrographic service appears to have the resources—either funds or surveying capabilities—to conduct extensive resurveying quickly.

[1] Present NOAA charts may use feet, fathoms, or meters. Conversion to the metric system, now under way, is expected to take 10 to 15 years. Thus, it is possible for a vessel's echo sounders, tide tables, and nautical charts to be in three different units. Electronic charting systems need to be capable of converting between all these measures and displaying consistent units.

[2] There are two methods of digitizing data. To produce raster digital data, the paper chart is passed through a scanner, which captures a digital image. The raster image can be displayed on a computer monitor but its features cannot be deleted or manipulated individually. An overlay for user input and chart updates can be added. Vector data, on the other hand, is produced by storing position and attribution information for each feature on the chart. Vector information is more difficult than raster data to gather but offers the benefit of selective manipulation and display. Vector data is required for ECDIS. Electronic charting display can use either type of data.

pected to take 5 to 10 years at today's rate of progress (Thomas W. Richards, NOAA, personal communication, April 30, 1993).

A question is whether the features of electronic charting systems have sufficient value to justify their near-term adoption without a corresponding improvement in basic hydrographic survey data and timely resolution of chart discrepancies.

Options for Immediate Action

There are no universal standards that, if met, would ensure that all electronic chart display systems performed at acceptable levels. *International standards could be developed for production, use, and updating of electronic charts; production and use of electronic chart display systems; and provision of automated corrections to electronic charts and other notices to mariners* (see Sandvik, 1990). In this regard, the current worldwide effort to evaluate the data standard for electronic charts, DX-90, is encouraging (Alexander and Black, 1993; Pendleton and Alper, 1992). Also, the IMO has promulgated provisional performance standards for ECDIS. Such standards could require that data be displayed exactly as provided by the relevant hydrographic office and that they be secure from corruption.

Options for Incremental Improvements

Accuracy and reliability are complicating factors in the effort to accord electronic charts the same legal status as paper charts. To help ensure the legal status of electronic charts systems in application, authorities could *require that electronic charting systems meet international performance standards and recommended practices (referred to as SARPS by the International Civil Aviation Organization [ICAO])*. Software could be designed to ensure that human operators do not inadvertently screen out important navigation information, based on criteria that must be met for safe operation.

To assure high reliability, *electronic chart data bases could be provided by or under the direction of national hydrographic offices* , which now produce paper charts. Norway and the United Kingdom have proposed developing international data bases. The International Hydrographic Organization (IHO) has been reviewing these proposals as well as the possibility of developing regional electronic chart data bases (Alexander and Black, 1993; Thomas W. Richards, NOAA, personal communication, April 30, 1993; Smith, 1993). *Hydrographic data for U.S. waters could be improved by conducting timely modern surveys to provide complete bottom profiles for U.S. waters and to correct chart discrepancies* . Ideally, ocean survey practices would have to be improved as well. This option would necessitate a commitment of substantially greater resources than now available for national hydrographic surveys.

The reliability of electronic charts could be enhanced further by the *development of automated means for incorporating chart updates and notices to mariners* concerning, for example, aids-to-navigation outages or buoys off station (Barber and Bass, 1992; Langran, 1992). This technology has been available for several years but has not been applied to this purpose. If the technology is not applied, a vessel would be required to maintain updates to the paper chart, a substantial and perhaps unnecessary chore that, from the operator's perspective, would be human-resource intensive in an era of reduced crew numbers.

Finally, the *provision of accurate, up-to-the-minute weather and environmental information* would enhance the safety of marine navigation through voyage planning. Electronic data transmission systems could be established for broadcasting forecast data on tides, currents, and weather as well as real-time observations of environmental conditions. This would be a value-added feature that is not integral or essential to an electronic charting system. The service could be provided by the Department of Commerce through the National Weather Service and NOAA or perhaps by commercial vendors. Services could be publicly funded with or without cost recovery (such as user fees), or offered on a subscription basis. Certain information such as channel depth survey data could potentially be provided directly to users such as pilot associations by the surveying authority. For example, the U.S. Army Corps of Engineers sends daily hydrographic channel survey data by facsimile to the Crescent River Port Pilots Association for miles 0 to 4 of the lower Mississippi River (Mark Delesdernier, Jr., Crescent River Port Pilots Association, personal communication, January 15, 1992).

Options for Long-term Development

Voyage planning could be further enhanced through *expanded deployment of real-time environmental information systems*, such as NOAA's Physical Oceanographic Real-Time System (PORTS)(briefly described in Appendix G), to provide data for all major U.S. Harbors. The PORTS system is an information acquisition and dissemination technology. The system integrates real-time current, water level, and wind measurements from multiple locations. Data dissemination is by telephone and includes modem dial-up (Appell et al., 1991; Bethem and Frey, 1991; NOS, 1990). (See *Weather and Environment Monitoring* for related discussion later in this chapter.)

Position Fixing

The Traditional Approach

Position fixing still relies heavily on traditional navigation techniques and technologies during a vessel's transit of pilotage waters. The process may or may not be difficult, depending on the availability of reference points and aids to navigation, visibility, and the frequency of maneuvering requirements. The process is much more difficult during periods of reduced visibility and darkness, when shoreline features, shore aids, and buoys may not be visible. (Buoys and other reference points may be obscured on radar by sea return or weather.) In any case, position fixing by conventional means leads to a determination of where the ship was when the data were collected, not where the vessel actually is. This is fine at sea but inadequate in pilotage waters, where the timing of maneuvering can be just as critical as in aviation with respect to ensuring a safe transit. There is unusually high interest among ships' officers and marine pilots in the emerging real-time position fixing technologies.

Using conventional techniques, a ship's position is determined by taking visual or radar bearings from fixed objects of known position or by obtaining latitude and longitude positions from electronic navigation instruments. At sea, ships' officers still sometimes use sextants to take sightings of the sun or stars, more to remain proficient in this traditional technique than to navigate. Taking sextant angles from fixed objects ashore is a traditional, highly precise position fixing technique but is rarely used in piloting, although sextant angles may still be used occasionally to precisely position buoys. Position data, regardless of source, must be plotted on a navigation chart to determine the position of the ship with respect to the voyage plan and the land, channel, or other features shown on the chart. Pilots, regardless of proficiency in these practices, are expected to determine positions based on expert knowledge of the local waterway using visual observations of local geography, aids to navigation, and radar presentations.

Watch officers usually plot positions on charts laid out on a plotting table installed in the pilot house. During this process, their attention is drawn away from other bridge team tasks. Plotting a fix can take 3 to 10 minutes or more, depending on mate proficiency; bridge layout; and operating conditions including visibility, familiarity with local geography and aids to navigation, and competing demands for the mate's services. The requirement for position fixes does not change when the vessel is under the direction and control of a pilot; this is one of the master's principal means of determining whether a pilot is performing effectively. However, difficult maneuvering conditions can quickly involve the mate or master in providing support to the pilot; for example, they may have to man the radar continuously in fog in a congested harbor. In such circumstances, there may not be adequate time to take and plot fixes in the normal manner. Further, in a narrow, winding channel, the taking of fixes is a full-time task requiring a dedicated navigation team, such as is typically found aboard Navy or Coast Guard vessels. For all practical purposes in such maneuvering conditions, the determination of the vessel's position is left almost entirely to the vessel's pilot, official or legal requirements for the master to maintain an up-to-date position plot notwithstanding. So, at the time that precise position data is most needed, it is also often most difficult to obtain; maneuvering is thus based on the pilot's position estimate. These are the times when a pilot's expert knowledge and skills are essential and put to the test. However, the pilot is affected by the same operational and environmental factors as the master and mate, factors which may affect the accuracy of the pilot's position estimate. Under such operating conditions, the master's command responsibility to oversee pilot performance with respect to navigation safety is academic unless the master is also a qualified pilot on the route. Electronic navigation technologies, discussed below, hold considerable potential to overcome these shortcomings in traditional navigation practices.

Mature technologies used for position fixing include paper charts; visual navigation aids such as lights, buoys, and ranges; enhanced radar navigation aids such as radar-reflecting buoys and racons; Loran C; and radio beacons used with radio direction finders (RDF). Two mature fixing technologies, RDF and Transit, are expected to be phased out and replaced by GPS while Loran, Decca, and Omega are programmed to continue in service early into the next century.[3]

The High-Technology Approach

Position fixing likely will be improved by several developing technologies that have yet to be completed or certified for navigation. These include GPS, the military satellite navigation system; DGPS, which is planned to provide civilian users with accuracy of 5 to 10 m in harbors and harbor approaches; GLONASS (Global Orbiting Navigation Satellite System), a Russian system similar to GPS; and electronic charting systems including ECDIS, which can display the ship's position, derived from DGPS or other position fixing equipment, directly on an electronic chart.[4] Of these, DGPS and electronic charting systems are most important for pilotage in U.S. coastal and navigable waters. Pilots responding to the committee's inquiry were more enthusiastic about DGPS than about any other highly sophisticated technology (Ramaswamy and Grabowski, 1992). Electronic charting systems would enable the master, pilot, and watch officer to visualize a vessel's position instantaneously relative to features displayed on the electronic chart. Available data can be taken from a sensor (such as DGPS) and placed into

[3] RDF fixes no longer meet modern requirements for navigation although RDF bearings remain useful for search and rescue purposes. The United States plans to terminate Transit in December 1996 (DOT and DOD, 1993). Omega is not expected to be terminated before the year 2005, and Loran C is to remain in use through 2015.

[4] The mariner must ensure that a ship's positioning systems and charts are based on the same horizontal datum and ellipsoid. Most U.S. nautical charts are based on the North American Datum of 1983 (NAD 83), which makes use of the ellipsoid specified in the Geodetic Reference System of 1980. The GPS uses the World Geodetic System 1984, which, for charting purposes, can be considered equivalent to NAD 83 (Donald Florwick, personal communication, October 30, 1992). In other parts of the world, however, many different datums and ellipsoids are in use.

context on an electronic chart display. Further, depending upon system features, the data that are displayed can be tailored or highlighted to meet specific needs, revealing, for example, safe operating depths. If an electronic charting system satisfied legal requirements for position fixing—the ECDIS concept—it no longer would be necessary to manually collect and process navigation data, except as may be necessary to confirm that electronic systems are functioning correctly.

Electronic charting system featuring an electronic chart and real-time positioning using differential GPS. (*Trimble Navigation*)

Although electronic charting systems and DGPS can be used separately, it is in their combined use that maximum benefits are obtained, because the detail on the electronic chart can be immediately related to position data. DGPS would feed ECDIS the most accurate positioning information available, and ECDIS would provide the real-time picture of the vessel's position, exploiting the position information for timely and effective maneuvering. A key barrier to achieving these benefits is that international performance standards have yet to be approved for ECDIS by the IMO and IHO, although such standards have been drafted. Standards are expected to be approved and operational by 1995. But for now, ECDIS has no official legal status as a replacement for paper charts. Estab lishing this status would require approval of international standards and port-state adoption of them. The mariners aboard the small number of commercial ships that carry electronic charting systems say they use them only as optional navigation aids. Other concerns about use of electronic charts include reliability and durability of electronic systems in a marine operating environment. Further, research on and development of these systems has yet to be completed (Alexander and Black, 1993).

In developing standards, it will be necessary to resolve the issue of what ECDIS is—whether it is equivalent to, more than, or entirely different from a paper chart in terms of function (Hebden, 1990; Mukherjee, 1990b). Because it is impossible to predict all the future operational modes or uses for a technology, overly specific parameters could limit optimal usage and further development. Past debates over ECDIS specifications have centered on such details as which route-monitoring functions should be displayed, and how far in advance—yet the technology had yet to be used. Questions of copyright and liability will need to be addressed (Dion, 1991; Ganjon, 1990; Gauci, 1990; Mackaay and de Kinder, 1990; Mukherjee, 1990a; Obloy, 1990; Troop, 1990; Wiswall, 1990). Most countries except the United States have copyrights to protect their investment in the cost of hydrographic surveys and in production of charts and data bases (Mukherjee, 1990a). (The Defense Mapping Agency [DMA] is seeking legislation to allow copyright of all or part of any mapping and charting products prepared by or for the agency [Thomas W. Richards, NOAA, personal communication, April 30, 1993].) There is also a safety concern that the data be used properly, although safety could be controlled through means other than copyright, such as by regulations requiring use of "official" charts. The draft performance standards for ECDIS specify the use of charts from national hydrographic offices. Thus, it is likely that NOAA's Nautical Charting Division will be a major source of data.

One possible model for handling ECDIS data is the system used by the Canadian Hydrographic Service (CHS) in managing the IHO Tidal Constituent Data Bank. The database contains astronomical information used to predict tides —information that has commercial value. The CHS refers commercial requests to the country that originally provided the data in question (CHA, 1990).

Supporting Technologies and Resources

An issue constraining the use of electronic charting systems and ECDIS is the availability of supporting technologies and resources, particularly the accuracy of radionavigation signals (Box 6-2). Eight to 20 m accuracy 2 dRMS (distance/root mean square) is required for system planning and development of radionavigation aids for the safe navigation of ships and tows in harbors, harbor approaches, and U.S. coastal waters. It is important to recognize that GPS is a Department of Defense satellite-based system. For civilian users including com

BOX 6-2 EVALUATING ELECTRONIC NAVIGATION SYSTEMS

In evaluating a navigation system such as DGPS, the most important factors are accuracy, system integrity, availability, and continuity of service (Braff et al., 1983). Three of these factors are concerned with safety; the exception is availability, which is concerned mainly with efficiency. All four factors are discussed below.

The total system navigation error when using GPS is the sum of sensor error (i.e., the accuracy of the GPS position readout) and steering error (that is, how well the vessel's steering system follows the intended track). The accuracy of DGPS, meanwhile, depends upon the accuracy of its range measurements and the multiple-satellite geometry with respect to the user, as quantified by the horizontal-dilution-of-precision (HDOP) factor. Thus, to attain high navigational accuracy using DGPS: (1) position determinations must be made when the HDOP is below a certain number (USCG, 1992), (2) the dimensions of the vessel must be taken into account (i.e., the position of the DGPS antenna must be known relative to the radar antenna and the pilot house), (3) the vessel steering system must be able to follow DGPS guidance commands in real-time, and (4) the range-to-shore transmitter should be within 200 miles (although longer range-to-shore distances have been used by the Coast Guard in Alaska).

Integrity is defined as "the ability of a system to provide timely warnings to users when the system should not be used for navigation" (DOT and DOD, 1993). The DGPS has an integrity function (USCG, 1992), which is implemented easily, because there is direct communication to the user's receiver, and the broadcast of differential corrections is monitored independently.

mercial marine applications, GPS provides horizontal accuracy to 100 m 2 dRMS, or approximately 95 percent of this accuracy (DOT and DOD, 1993). This limited accuracy is due to deliberate degradation of the system by DOD; normally, accuracy would be in range or 20 to 30 meters (Donald Florwick, NOAA, personal communication, October 30, 1992). To overcome this performance limitation and to minimize other systemic signal errors, GPS can be augmented by differential corrections to its range measurements based on the precise location of a reference antenna, an approach referred to as differential GPS, or DGPS (Alsip et al., 1992; USCG, 1992). The present attainable 2 dRMS accuracy of DGPS is roughly 5 to 10 m (Alsip et al., 1992); accuracy may improve with the next generation of GPS receivers, as receiver errors (noise and multipath) are minimized (Cannon and Lachapelle, 1992).

The GPS is scheduled for full operation capability by mid-1995, while DGPS, a system originally developed by the Coast Guard to support its aids-to-navigation mission, is scheduled to be in place in 1996. A DGPS system is also being developed by the U.S. Army Corps of Engineers for use in the inland river system (Burgess and Frodge, 1992). Full use of ECDIS depends on the availabil

The availability of a navigation system is the percentage of time the service is usable (DOT and DOD, 1993). As discussed earlier, accuracy depends upon satellite geometry as defined by the HDOP. For vessel navigation, four satellites are required to determine latitude, longitude, height, and time; if the height above the ellipsoid is known, only three satellites are required. Also, the difference between mean sea level and the NAD 83 ellipsoid must be corrected. Thus, if data exist for these corrections for harbors and harbor approaches, the requisite 99.7 percent availability (USCG, 1992) should be met. The level of GPS coverage in terms of HDOP usually can be predicted before DGPS is used, so a vessel's navigation profile can be planned in advance. INMARSAT-3 communication satellites were planned to provide additional GPS-type signals (Kinal and Singh, 1990) by mid-decade, with dual-redundant signal coverage of both coasts. These satellites were to be built with this capability.

Continuity of service is the same thing as reliability, defined as "the probability of performing a specified function without failure under given conditions for a specified period of time" (DOT and DOD, 1990, 1993). In aviation, there is a specific requirement for continuity of service for precision approach and landings (ICAO, 1985). One requirement specifies the probability of the landing service functioning properly during a critical time interval of the approach; if the landing system were to fail during this interval, the safety hazard would be significant. This type of requirement may need to be applied to DGPS usage that would change current practices (Atkinson, 1991). Similar requirements have already been established for vessels using DGPS in various defined maneuver categories in restricted waters (Creamer et al., 1993).

ity of DGPS. The rapid development of technologies such as ECDIS may not be retarded by GPS maintenance problems, but funding responsibilities for long-term maintenance of the satellite system (or subsequent systems) have not been established. Long-term maintenance of GPS and funding for this need to be assured to underwrite the long-term application of navigation equipment relying on DGPS.

Options for Immediate Action

The development and approval of minimum international standards for ECDIS would spur the research and development needed to refine the technology and establish its legal status. As noted earlier, no national standards have been set for commercial systems,[5] but several international initiatives are under way

[5] Many recreational boaters use low-cost systems that provide real-time, precision navigation information. These systems calculate, with varying degrees of precision, the position of the vessel from Loran, GPS, DGPS, or other electronic systems and display it in relation to a programmed voyage plan, electronic chart, or both.

to standardize specifications for data bases, display formats, and equipment performance. As emphasized earlier, performance-based standards would be preferable to equipment-based requirements.

The liability issue is more complicated. Liability must be assigned for imperfect data bases,[6] improperly scanned or displayed hydrographic information, mistakes in transmission of chart corrections, and misuse of the technology. (A key legal problem will be how to prove cause and effect; that is, how to prove what appeared on the display at a given moment in the past, such as at the moment of a grounding. Draft performance standards for ECDIS require data to be stored for eight hours.) To encourage development of ECDIS in spite of the potential liability problems, *the U.S. government could indemnify chart makers and manufacturers of electronic charting systems (including ECDIS) from any claim attributed to inaccuracy in an electronic data base provided by the government*. Indemnification of aeronautical chart makers has been legislatively required in only limited situations (P.L. 99-190). Although the law is reported to have been interpreted to include electronic data bases provided by the government (Schultz, 1992), the legal status of this position is uncertain. In view of the potential benefit of electronic charting systems to improved navigation safety, it is desirable that the resolution of legal issues proceed in parallel with the further development and introduction of the technology.

According to Daniele Dion, a maritime-law adviser to the Canadian government, the nature of liability could change in the transition from paper to electronic charts. Manufacturers could be liable if they made an inexact scan of the official hydrographic chart, or if the design (e.g., scale, symbols, graphics) of the chart were misleading, regardless of whether the contents were accurate (Dion, 1991). "Needless to say, the standard of a reasonable, prudent mariner will also be higher, and the criteria determining a vessel's seaworthiness will be higher" (Dion, 1991).

Although implementation of ECDIS will proceed regardless of legal issues because of the potential to significantly reduce operational risk, obtaining full operational benefits from this important technology could be constrained by current legal and regulatory requirements, which were written with traditional technologies in mind, that affect navigation practices on the bridge. It would be helpful to *review, and possibly modify or repeal, legal and regulatory require*

[6] As noted earlier, survey total coverage is a problem with paper charts. Even so, few liability cases have been filed on the grounds of inaccuracy in nautical charts. The courts did set forth a number of principles in the 1982 case of *Warwick Shipping Ltd. v. The Queen* , ruling that the preparation and publication of a chart by a public authority does not imply that the authority has possession or control of the channel in question, as would be required to establish direct liability in Canada. The court also ruled that soundings "have no absolute value; they do not guarantee that indicated depth will remain or be maintained as shown, unless there is some indication to that effect on the chart" (Dion, 1991).

ments and expectations for bridge team operations and procedures that unnecessarily constrain the application of high-technology navigation systems, to ensure consistency with ECDIS operations and to eliminate unnecessarily duplicative or counterproductive actions.

Options for Incremental Improvement

Several mature technologies could be altered or improved to support the use of new technologies. For example, *even if ECDIS became the legal chart standard, a paper chart might still be needed as a backup* to cover the possibility of system failure or disruption. An alternative to existing paper charts may be suitable. For example, a backup system might consist of periodic hard copies derived from the electronic chart data base aboard the vessel. (The IMO draft performance standards for ECDIS require a computer backup.)

In addition, to meet pilots' expectations arising from the increased accuracy of onboard navigation systems, *the accuracy of short-range aids to navigation may need to be improved*. Any conflicts between real-time navigation input and charted buoy positions would become more obvious with real-time position fixing capabilities.

Some improvements in short-range aids already are being made. Most aids maintained by the Coast Guard have been converted to solar power (with backup power sources). These modifications to short-range aids have extended service life, improved reliability, and reduced maintenance needs (Charles Mosher, USCG, personal communication, January 11, 1993). The Coast Guard is also switching from the old radar beacons mounted on buoys to frequency agile beacons and is planning to increase the number of beacons as well. The new beacons are expected to help mariners differentiate between buoys and ships on the radar display. In addition, high-power range lights have been developed to improve mariners' ability to see these aids in areas where there is significant background lighting (such as near populated areas); these advanced range lights have been installed in locations such as the Chesapeake Bay, where pilots report improved ability to distinguish navigation aids from background lights (Charles Mosher, USCG, personal communication, January 11, 1993). Finally, optics research and development is under way to increase the intensity of observed light emitted by rolling buoys.

Other possible improvements would include *more accurate and reliable placement of buoys and other fixed aids, wider distribution of ranges and high-intensity racons to support increased expectations for continued port operations in poor visibility, and development and installation of electronic ranges for use with either installed or portable navigation systems in poor visibility*. The Coast Guard has already authorized the use of DGPS for positioning buoys. A concept for an interactive, portable electronic charting system, the portable communications, navigation, and surveillance (PCNS) system, is described later in this chapter.

It might be helpful to *accelerate certification of GPS for two-dimensional navigation and to accelerate introduction of DGPS service in all major ports*. In addition, *planning and funding could be stepped up for development and distribution of electronic chart data bases, particularly for harbors and harbor approaches*. Likewise, *the schedule for surveys and chart revisions could be accelerated (by increased funding) to support the increased requirements for chart accuracy demanded by the DGPS/ECDIS display*. The new surveys could be conducted using state-of-the-art technology to provide 100 percent bottom coverage in significant areas. And, to ensure that new technologies are used properly to reduce risk, it would be helpful to *explore the human factors aspects of using electronic charts (such as boredom, fatigue, and human–machine interaction issues), including training needs*.

Options for Long-Term Development

To accommodate the introduction of advanced technologies, *long-term plans could be developed for enhancing and expanding the current system of short-range aids to navigation to meet expected needs*. The Coast Guard, Army Corps of Engineers, local port authorities, and others involved in providing and maintaining the system could review existing policies and priorities and develop such plans, which could include early identification of funding needs.

Finally, *long-term plans for production of charts and other navigation products and services could be reviewed* by the National Ocean Survey (NOS), the DMA, the Corps of Engineers, the Coast Guard, and other government agencies to make sure the products offered are those required by users to support changing operations.

Communications

Bridge-to-bridge voice radio communications have become essential for coordinating vessel interactions. However, use of this medium for data exchange is inefficient, error-prone, and subject to interference (NTSB, 1991b). Unauthorized or inappropriate use of marine radio frequencies is reported at times to interfere with bridge-to-bridge communications, and to a lesser degree, with communications between vessels and VTS systems. Both VTS and bridge-to-bridge communications are often affected adversely by congestion on designated radio frequencies during times when bridge-to-bridge communications are most useful. Conditions when this occurs include adverse weather conditions, especially fog, and severe traffic congestion or emergencies in the waterway that affect traffic flow. But the larger issue is that VTS (where available) relies heavily on voice radio as the primary medium for data exchange. Problematic VTS communications practices also include selective screening of navigation information by shore-based personnel, transmission of important information at inop portune times (for example, while two vessels are engaged in communications to avoid or alleviate an emergency situation), and reliance on monitoring of all transmissions on VTS frequencies as a means of acquiring a comprehensive picture of current traffic. These factors compound communications problems by contributing to information saturation (see Chapter 5; Ahearn, 1992; Burnett, 1988; Ives et al., 1992; Young, 1992, 1994). Such effects can compromise rather than increase safety, a factor that merits legal consideration in the application of VTS (Barber and Dunning, 1989; Corbet, 1989; Gold, 1984, 1988).

While at sea and approaching the coast, mariners can use satellite communications (SATCOM) to communicate via satellite to conventional land telephone circuits (Fear, 1989; Mottley, 1992). A number of improvements are being made to SATCOM, the use of which has been limited by cost. for example, the standard antenna costs $30,000 and weighs 200 pounds. (Joseph D. Hersey, USCG, personal communication, January 12, 1993). Per-call communications costs are also expensive and perhaps prohibitive: $10 per minute with a 3-minute minimum.

New, lightweight systems for both data and voice communications are being introduced. In addition, the Coast Guard reports that it has improved the overall communications system through enhanced connections to marine safety centers and an improved process for sending navigation warnings (Joseph D. Hersey, USCG, personal communication, January 12, 1993). Mariners also may use cellular telephone to coordinate delivery of supplies. In a few cases, real-time tidal or other environmental information can be obtained through cellular access to reporting systems. During the 1988 port-wide tugboat strike in New York Harbor, cellular phones aboard some vessels were used by masters as a means to privately schedule vessel departures with Vessel Traffic Service New York (Ives et al., 1992). However, these capabilities have been employed sparingly.

Options for Incremental Improvements

The overloading of frequencies is attributed in part to pleasure boats and in part to commercial fishing vessels. (The Bridge-to-Bridge Radiotelephone Act calls for use of Channel 13 by all vessels over 20 meters in length.) It might be useful to *enforce aggressively regulations controlling the use of VHF radio channels to remove unauthorized users*. This may or may not be a practical option depending upon local circumstances; it might be impractical, for example, where there may be hundreds of small commercial or recreational vessels underway at one time.

Communications could be improved in VTS operations to reduce the potential for human error and to increase the efficiency and effectiveness of VTS–user interactions. (A related option for improving VTS surveillance capabilities is discussed in the next section.) Electronic data transmission capabilities are already available for naval uses and have appeared in prototype form in commer cial marine operations. Such capabilities could be used to enhance the completeness and user-friendliness of VTS information provided to vessels for onboard interpretation and use. Concurrently, the VTS role could be shifted from interpretation of navigation information as a intermediary to high-level safety oversight of the ever-changing traffic situation. While this concept is under examination by the Coast Guard and a few marine pilot organizations for local VTS-like applications, it is not an element of present VTS operating procedures in the United States (Ives et al., 1992). The Coast Guard reports that the concept is being more fully developed in the agency's VTS 2000 acquisition program, but it is not anticipated as an element of the next phase of Coast Guard VTS installations (see Chapter 5). Another option would be to *improve radio-circuit discipline, instituting standard language and procedures similar to those used in air traffic control communications*.

A technology advance that could be put to use for electronic data exchange is a portable interactive communications system, generically referred to as a PCNS (portable communication, navigation, and surveillance system). The PCNS system could be carried aboard by pilots to provide real-time, locally specific navigation information; to supplement standard shipboard navigation systems; or to provide an alternative if shipboard equipment is deficient.

PCNS system architecture could be based, for example, on an experimental Swedish system used for navigation and automatic dependent surveillance (ADS) of aircraft (Nilsson, 1992). DGPS would be used as the position sensor for both navigation and ADS; in the latter case, position and velocity would be transmitted by a VHF data link. The PCNS system also would receive, process, and display information broadcast by the local collection site, which could be a VTS (Galyean, 1992), and by other nearby users. To be successful, the PCNS system would have to be lightweight, small enough to be carried and used easily, and sturdy enough to survive the pilot boarding process and the marine operating environment. All essential vessel and traffic data could be transmitted to and from a shore-based collection and retransmission station.

The PCNS concept appears to be technologically feasible in the near term. Such a system is being developed for private operation in the Port of Tampa based on a 2-year study by the Greater Tampa Bay Advisory Council in which a number of marine pilots participated (John C. Timmel, Tampa Bay Vessel Information and Positioning System, personal communication, July 16, 1993).

An important communications advance is expected with the advent of digital selective calling (DSC). Mariners will no longer need to monitor the VHF Channel 16 for establishing contact with other vessels and rescue centers; the implementation of DSC will provide the capability for automatic alerts (Joseph D. Hersey, USCG, personal communication, January 12, 1993). DSC potentially could be applied to improve safety in pilotage waters, as discussed later in this chapter, and it is a feature employed in the Prince William Sound ADS system.

Portable DGPS receiver with electronic chart. (*Raytheon Marine Company*)

However, DSC may not have the capability needed for broad-based VTS or ADS applications.

Options for Long-Term Development

Marine pilots responding to the committee's inquiry suggested that voice radio frequencies be established for the exclusive use of professional navigators and pilots (Ramaswamy and Grabowski, 1992). To alleviate channel saturation, *additional VHF channels could be made available for commercial marine voice communications*. If necessary, *channel bandwidth could be narrowed consistent with currently available tuner technology*. The Coast Guard has established an alternative frequency for a portion of the Mississippi River, a strategy that might be pursued elsewhere (Edward LaRue, USCG, personal communication, January 11, 1993). The Coast Guard and the Federal Communications Commission (FCC) were soliciting comments through June 1993 on possible communications-related regulatory changes, including the splitting of the VHF band into smaller channels (Joseph D. Hersey, USCG, personal communication, January 13, 1993).

Collision Avoidance and Surveillance

Collision avoidance and surveillance depend primarily on visual lookout, and the use of radar and Automatic Radar Plotting Aid (ARPA). In poor visibility, radar and ARPA become even more essential. Mariners also listen for the sounds of other vessels, although this technique seldom provides a very accurate indication of distance or direction.

Where available, VTS systems can provide ships with valuable information about vessel traffic and other hazards in harbors and approaches. Acquisition of essential information and effective safety oversight requires a combination of independent and dependent surveillance (Box 6-3).

A variety of emerging technologies integrate collision avoidance and surveillance with other functions, such as position fixing and track keeping, or are intended to support one-person bridge operation. These integrated systems include electronic charting system display of ARPA targets or radar images; use of radio frequency data links to provide ADS information about other vessels (e.g., identity, location, speed, course) on the ARPA or electronic charting system

ARPA radar in use "aboard" a full-mission ship bridge simulator. (*STAR Center Dania, Florida, American Maritime Officers*) displays; enhanced low-light video displays and night-vision goggles to assist in night lookout; and, to assist in poor visibility, amplified audio from directional microphone arrays to discriminate sounds and their relative directions.

Options for Incremental Improvements

Existing radar/ARPA technology is not entirely adequate. Pilots responding to the committee's correspondence said their most pressing technological need was for a highly improved radar system, particularly with improved target acquisition (including buoys) during squalls (Ramaswamy and Grabowski, 1992). ARPA, meanwhile, does not have the resolution to solve problems involving close encounters, nor can it generate solutions quickly enough for transits requiring frequent maneuvering, such as in narrow, winding channels (Hosoda and Takagi, 1988; Zabrocky, 1992). Pilots also expressed concern about the delay in ARPA display of computerized information, as well as about the lack of standardized consoles mentioned earlier.

To take advantage of the accuracy of DGPS-derived course and speed-overground values and advances in radar and video processing, *new ARPA functions and display capabilities could be developed*. In addition, *the international ARPA standards that require speed through the water measurements do not allow for more precise speed determinations using DGPS and could be reviewed and revised as necessary*. Improved onboard plotting of targets is also possible, through use of automatic dependent surveillance shipborne equipment (ADSSE), discussed later in this chapter. In addition, integrated navigation systems, also discussed in more detail later in this chapter, could be developed that include display of ARPA targets and radar video (along with functions included in the ECDIS display; Royal Institute of Navigation, 1993). Also, *standardized outputs from ECDIS and other integrated systems could be used to support data transmission from ship to ship and to shore stations, such as a VTS*. Finally, *commercial and military systems for low-light video and directional sound discrimination could be adapted and incorporated into these integrated systems*.

Another way to improve surveillance would be to *revise procedures for VTS interactions with vessels, in order to reduce dependence on voice communications and to take advantage of new technologies such as ADS*. The use of ADS for surveillance could have significant operational advantages over radar. ADS offers greater accuracy and coverage than does radar in providing position, heading, and speed data, and it is also less vulnerable to environmental interference. The vessel tracks displayed at a vessel traffic center would be identified automatically and free of clutter. The periodic vessel broadcast of position, velocity, and intent also could be received and processed by nearby vessels as a complement to ARPA. The ADS/VTS system mandated by the Coast Guard to satisfy Oil Pollution Act of 1990 (OPA 90) requirements for tanker operations in Prince William Sound will provide an opportunity to evaluate this concept, although in a low-traffic-density operating environment. Lessons from this application are expected to provide valuable insight for assessing the potential of ADS applications for future use in marine traffic regulation—*if* adequate performance information is collected during system implementation and operation.

BOX 6-3 VTS SURVEILLANCE

VTS surveillance capabilities consist primarily of communications (audio surveillance) and radar, sometimes supplemented by visual overlooks and closed-circuit television monitoring of selected harbor areas. The equipment ranges from basic to integrated displays that, in advanced display, include video maps of port features. Independent surveillance, requiring no cooperation from vessels, is used to monitor vessel operations throughout the VTS area. Dependent surveillance, requiring interaction with the vessel, develops vessel-specific information. This information ranges from required radio reports to ADS, in which data such as position information are transmitted electronically to the VTS. Both forms of surveillance are needed, depending on the marine traffic regulation objectives for the VTS service area.

VTS electronic surveillance provides an all-weather capability for identification of vessels participating in the VTS as well as information of varying completeness on other operations or emergencies in the service area. Completeness and accuracy of information can be verified only partially through contact with other vessels. Precise position information is not available, because radar, while providing an all-weather capability for determining vessel positions, rarely identifies vessels. Vessel identification is available from the radar only if the vessel is equipped with a transponder (rarely used) or the radar feeds are integrated into an ADS display. However, a VTS operator's route and traffic knowledge and radar interpretation abilities typically permit identification of types of vessels; vessel names then need to be correlated with data obtained by voice radio communica

Options for Long-Term Development

At present, DSC is the only practical data link available for ADS of vessels through VTS systems. It is not bandwidth efficient (that is, the signal structure is not efficient) by contemporary standards, so it might not be adequate for ADS/VTS in a busy port. Widespread implementation of ADS/VTS could overload VHF communication channels [7] even beyond current levels of saturation. The

[7] Communications loading could be a major obstacle to ADS in ports such as New York or Puget Sound, where a high number of vessels (e.g. 40-60) may be tracked concurrently. DSC would require multiple VHF radio channels would to accommodate high-density vessel traffic operating environments, necessitating allocation of additional VHF frequencies for marine use. Such a requirement would appear to require regulatory changes.

tions, visual data, or operating schedules (e.g., ferry boats) as available. The radar display also can provide secondary indications of non-participating traffic, such as recreational vessels, as well as squalls moving through an area (radio reports are the primary source of this information).

Closed-circuit television, including low-light and infrared television, is used in some VTS centers. This surveillance medium can be used for vessel identification, detecting vessel or port emergencies (such as vessel loss of control or fires), and assessing visibility. However, except where a vessel passes directly in front of the camera or a fixed reference point, television can provide only approximate locations. Other limitations are that television does not provide an all-weather capability, it is inherently short-range (even with magnification capabilities), and it loses much of its effectiveness at night and during periods of reduced visibility. Infrared sensors have been used on a very limited basis.

The latest VTS display systems provide automated features that can acquire and track targets and display track histories to facilitate interpretation of traffic situations. In the United States, few VTS or VTS-like systems have advanced displays other than ARPA. A Coast Guard-mandated real-time position-monitoring system is being implemented for Prince William Sound to satisfy the intent of OPA 90 provisions. The Coast Guard has also established a VTS acquisition program—VTS 2000. A Coast Guard-industry consultative body assisted in developing an operational concept upon which future Coast Guard-operated VTS equipment requirements will be based.

Sources: DOT and DOD, 1993; Herberger et al., 1991; Ives et al., 1992; Young, 1994.

latest study on DSC loading was completed in 1986 (Paul Ornstein, personal communication, December 16, 1992). The same methodology is being applied to a study of ADS/VTS by the International Radio Consultative Committee, but, as of early 1993, that study had not been completed. For the future, the Coast Guard is looking at other means for data communications, such as satellites and highly efficient data transmission schemes for VHF. A more modern system could transmit many more information bits than can DSC in the same radio bandwidth.

Channel loading is directly proportional to ADS requirements for vessel position updates; therefore, these requirements must be known to conduct an accurate loading analysis. The committee made a number of informal inquiries to industry and the Coast Guard to determine whether a definitive set of operational requirements for ADS existed. No such guidelines were found. Opinions as to the optimal position-update interval for ADS ranged from 10 seconds to several minutes, depending in part on the vessel's situation and personal viewpoint. Thus, *a comprehensive analysis may be needed of requirements for ADS* *data communications*. The results could be used in a study of the potential for DSC channel loading related to widespread implementation of ADS/VTS.

Workstation-based VTS operator station. The latest-generation systems integrate surveillance, tracking, electronic charts, radar overlays (or underlays), data management, record and playback, and expert systems incorporating local port rules, procedures, and operating practices to provide a watchstander with a comprehensive representation of traffic activity and predictive capabilities. (*Martin Marietta Ocean, Radar and Sensor Systems*)

In addition, because DSC must be used as an international standard in the near term, *the Coast Guard could accelerate its investigation of more efficient data communications systems*. One possibility is the application of time division multiple access (TDMA), using GPS to define the time frames. An experimental TDMA system in Sweden is capable of providing 225 to 375 ADS reports every 6 to 10 seconds, for 225 to 375 vessels, in a VHF channel with a bandwidth of 25 kHz (Nilsson, 1992).

Steering and Track Keeping

Establishment of a marine traffic regulation system analogous to that employed in air traffic control would require, among other things, that vessels have the capability to precisely adhere to assigned paths (see Chapter 5). Although precision navigation and adherence to planned tracks are technologically feasible, they seldom are practiced in commercial marine operations. These approaches are employed on a limited basis under very select operating conditions (Box 6-4).

Most ships use a much more traditional approach. Steering is controlled by an autopilot at sea and a crew member in confined waters. As most ships do not have electronic charting systems or other real-time systems to display the ship's progress along a planned trackline, a course typically is ordered by the watch officer or pilot as a compass heading, which is maintained by the helmsman or quartermaster or set in an autopilot. The watch officer determines the heading by examining the past course plotted on the chart, noting any deviations from the intended track (set and drift), and predicting a heading that will provide a course that follows the voyage plan.

At sea, where relatively large deviations can be tolerated, plotting may be done every half hour or so; these intervals must be smaller while approaching or in a harbor. In confined areas where rudder orders are often used for steering, the course usually is monitored in real-time by visual observation of fixed aids to navigation, landmarks, or the radar display.

In very confined waters, the master or pilot frequently controls the ship by ordering specific degrees of rudder movement rather than courses to steer. This method of steering provides the necessary control to offset or counteract the effects of physical forces but requires precise and reliable communications, considerable skill, and a very good understanding of the ship's handling characteristics and the hydraulic nature of the waterway. A pilot may also use a ship's anchor to enhance control over a vessel in certain confined maneuvering situations (Armstrong, 1980; Hooyer, 1983; MacElrevey, 1988).

A few ships are equipped with steering systems that are connected to and integrated with electronic charting systems, allowing the ship to automatically maintain a preset, minimum distance from the planned track line (a procedure known as cross-track error control). Ships that have an electronic charting system or radars displaying the voyage track line, but no interface to the autopilot, are steered in the traditional manner, but orders are based on visual observation of the cross-track error on the display.

Mature technologies used in steering and track keeping include electrohydraulic steering control, magnetic compass, gyroscopic compass (commonly referred to as a gyrocompass, or simply, the "gyro"), rate-of-turn indicator, Doppler speed log, and autopilot. Some significant improvements to steering and track keeping capabilities are expected in the near term; these include new sensors for speed over ground, heading, rate of turn, and pitch and roll. These advanced instruments, which will exploit the high accuracy of DGPS, are expected to be significantly more accurate and reliable than are current indicators. Most new GPS receivers already display speed over ground. This information, when improved using DGPS corrections, is more accurate and reliable than speed through water as measured by the Doppler speed log.

In addition, improved autopilots are being developed. The idea is to use sophisticated algorithms and advanced digital programming techniques such as neural networks to provide precise turning radii and maintain an accurate track.

BOX 6-4 TURNING A SHIP

During turns, vessels "advance" in the direction of the original course and "transfer" to the right or left at right angles to the original course as the vessel slides through the turn. The turning circle can increase significantly with higher speeds. Advance and transfer can be calculated for constant rudder angles and for vessel speed for deep water conditions. In shallow water (depths of 1.2 times a vessel's draft or less), hydrodynamic effects can cause the turn diameter to increase up to twice that for the same ship in deep water. Generally, the shallower the water, the more pronounced the effect. Very little data are available for determining the shallow water turning diameters of commercial vessels; field measurements in the range of 10 percent under-keel clearance or less have not been made. A vessel's directional stability generally increases and steering improves as water becomes shallower, except if a ship squats by the head as the result of hull form, draft, and trim. Negative directional stability adversely affects the ability to control a vessel during a turn. The turning radius can be altered by changing propeller revolutions, rudder angle, or both. Once a turn has started, additional revolutions can be applied in large amounts for very short periods to accelerate the vessel, rapidly increasing the turning moment and reducing the turning radius, especially when large rudder angles are applied simultaneously (Crane, 1979; Hooyer, 1983; MacElrevey, 1988; Maloney, 1985; NRC, 1985, 1992a). The turning radius can also be altered through skillful use of bank cushion and suction effects, use of anchors, use of rotational forces available from twin screw vessels, and, if installed, use of a bow thruster or an innovative rudder system.

Rudder angle can be effectively applied to maintain a constant radius turn from a fixed reference point, overcoming uncertainty in advance and transfer calculations for shallow water operations. A large rudder angle is used to initiate a constant radius turn in order to quickly attain a pre-planned, calculated rate of turn. In order to achieve the planned radius, rudder angle is then adjusted to maintain the correct rate of turn. Various methods can be used to monitor and maintain the rate of turn. This technique is used to adhere to precise paths during turns for vessels that can become dynamically unstable in shallow waters, for example, large passenger ferries operating between Sweden and Finland in the Baltic Sea. The success of the technique, which can be done manually or as a computer-aided maneuvering evolution, is in part derived from using the same vessels on the same pilot routes with the same masters and watch officers. Considerable piloting skill is required, and the master and one or more watch officers are present during the most difficult maneuvering evolutions (Gyldén, 1987a,b, 1989, 1990; Herberger et al., 1991; Pettersson and Gyldén, 1982).

A Small Business Innovative Research project sponsored by the Maritime Administration (MARAD) is evaluating the application of neural networks for an improved autopilot. Neural networks mimic the functions of the brain. They learn the attributes of the system in which they operate by observing and recording repetitive procedures and correlating the observations with programmed control inputs and environmental variables. However, despite all this technological potential, most current autopilots use algorithms that do not model a ship's characteristics in shallow water very accurately.

Other emerging technologies for steering and track keeping are related to integrated systems, discussed later in this chapter.

Options for Incremental Improvements

Existing steering and track keeping technologies are relatively mature. Incremental improvements in these functions depend on development of integrated systems and their components, discussed in this chapter.

Options for Long-Term Development

To enhance the near-shore utility of autopilots, *improved algorithms could be developed for predicting the turning rates and radii of ships in shallow water*. Advanced autopilots have been shown to steer with much greater precision than does the typical helmsman. Computer-aided steering[8] has been demonstrated through passages for which hand steering is not suitable (Gyldén, 1987b, 1989, 1990; Herberger et al., 1991; Wallenius Lines, 1991). However, OPA 90 now requires hand steering in certain pilotage waters, as use of an autopilot may have been a factor in the *Exxon Valdez* grounding (Davidson, 1990; NTSB, 1990). Hand steering can be very effective and in some cases is the preferred method of steering, depending upon the proficiency of the helmsman and the circumstances of use (Gyldén, 1987a,b). But, many pilots contacted during this study reported that helmsman skills have deteriorated. To some extent, this is the result of increased use of automatic steering systems and the more limited hand steering opportunities (Gyldén, 1987b). To take advantage of technical advances in steering systems, *regulations could be established, or the existing U.S. law amended, to allow the use of high-performance autopilots in pilotage waters and under certain operating conditions if superior steering can be demonstrated.*

Track keeping also could be improved by use of ECDIS, which can provide real-time position fixing more accurately and consistently than can plots on a

[8] These systems are actually a combination of ECDIS and a piloting expert system. The ferries are manned by permanent ship's officers, qualified to pilot on these routes, who have the expert knowledge necessary to judge the accuracy of computer-generated solutions and are in a position to override these solutions if necessary.

paper chart. But current regulations do not allow for the independent use of a system such as ECDIS. To facilitate the effective use of ECDIS, *regulations could be issued to establish ECDIS and an electronic chart data base as equivalent to manual plotting, provided that suitable performance and operational objectives and standards are also developed and observed.*

Decision-Making Aids

Integrated navigation systems have potential to enhance the immediacy and precision of information available on the bridge and, by consolidating displays, reduce the work load on the crew. Integrated systems are expected to reduce both accident risk and work load substantially, thereby supporting shipping companies in their efforts to reduce crew numbers and costs. Piloting expert systems can enhance safety further by reducing information overload and promoting timely and accurate decision-making (Box 6-5).

Integrated systems have evolved as a result of digital controls and instruments and the increased capabilities of low-priced microcomputers. Most new marine controls and instruments are designed to accept inputs and outputs meeting a common standard, so they can be integrated easily and can communicate with microcomputers. These computers are capable of running very powerful programs that can handle, quickly and reliably, many navigation and maneuvering tasks, as well as engineering and cargo/ballast monitoring and control.

Current integrated technologies have been applied to four types of systems: ADS; PCNS; integrated bridge systems (IBS)(Alexander and Spalding, 1993; Hederström and Gyldén, 1992; Marine Log, 1993); and integrated ship control system (ISCS), which, in effect, integrate control of all other ship's systems with an IBS (Kasai et al., 1992; Kristiansen et al., 1989).

The consolidation of bridge displays is a significant benefit. (The task performance benefits are obvious if the IBS is compared with the traditional bridge layout described in Appendix G.) For the first time, the mariner is able to see and understand quickly the relationship of the ship to the environment. The three basic elements of the system are the digital nautical chart, DGPS positioning, and radar overlay. These provide the mariner with position relative to the surrounding land, hazards to navigation, aids to navigation, and other vessels.

Options for Incremental Improvements

Bridge team management and decision-making could be improved through accelerated development and use of integrated navigation systems. However, as technology becomes increasingly integrated, the issue of standardization becomes more important. Incompatibility of technologies will inhibit their integration. Most marine controls and instruments are designed to accept inputs and outputs meeting interface standards set by the National Electronics Manufacturing Asso

BOX 6-5 SHIP CONTROLLABILITY AND PILOTING EXPERT SYSTEMS

The controllability of ships in restricted waterways is an issue of substantial concern to pilots, ship operators and owners, and port developers and managers (Hwang et al., 1989; Van Amerogen et al., 1978; Veldhuyzen and Stassen, 1977). In congested waters, ship masters, mates, and pilots are inundated with data, which must be integrated quickly to make crucial piloting decisions (NAS, 1981). To compound the stress, these decisions often must be made after lengthy watches, and by increasingly smaller watch teams. The result, all too often, is information overload, and a breakdown of the decision-making process. Indeed, the present situation has been described as error-inducing, meaning the configuration of the many components induces errors and defeats attempts at error reduction (Perrow, 1984).

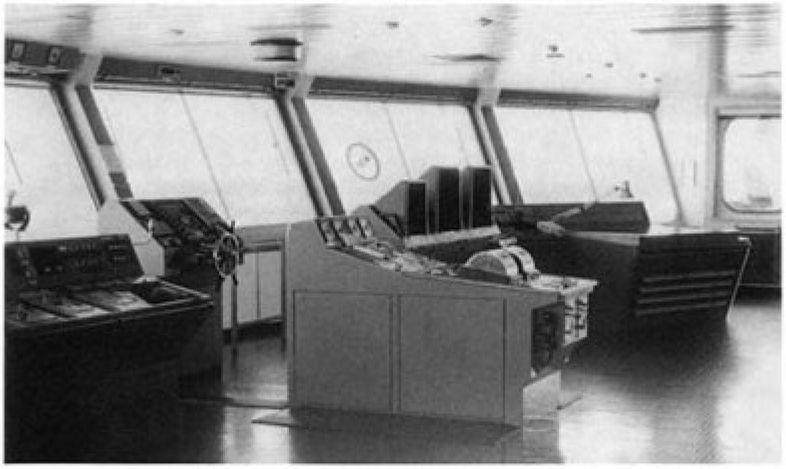
Piloting expert systems—whether stand-alone, embedded within an integrated bridge system, or real-time knowledge-based control systems—could improve this situation by supporting reasoning tasks. These systems are expected to make recommendations for track keeping, maneuvering and collision avoidance, and good seamanship (Grabowski, 1989; Grabowski and Wallace, 1993).

Expert systems already are available for some engine and engineering functions. These rule-based systems make use of vibration analysis, temperature and pressure readings, and other indicators to anticipate changes, problems, and possible failures. The systems then correlate the symptoms with programmed expert actions and either display advice to the operator or perform the action. The degree to which these systems can relieve the watch officer depends on the extent of programming and the completeness, accuracy, and reliability of the sensors.

Piloting expert systems use input from radar/ARPA, electronic chart systems, and bridge instrumentation in ways similar to those employed by the engineering expert systems, but the piloting systems are more complex in that they tend to be more dependent on heuristic, or "rules of thumb." Alerts, alarms, and recommended course changes are the primary outputs; information also is provided about the current track, underway conditions, next track, and weather and visibility. On-line use supports piloting and navigation decisions, and off-line use can provide training opportunities through simulation.

Piloting expert systems often are developed as intelligent nodes in real-time shipboard local area networks. These systems most often are constructed with expert system shells, operating within a multitasking system (i.e., UNIX, A/UX, XENIX); they typically are developed on engineering workstations, although some systems have been constructed on microcomputer platforms. Expert systems often encompass (1) a set of interface routines that permit communication between the expert system and the parent software, (2) a set of electronic charts that provide a real-time view of vessel position, and (3) the expert system and positioning equipment. Piloting expert systems are dependent upon the quality of the positional input and the quality of the electronic chart displays, which often are used to reflect the positioning information. Therefore, the coupling of these complementary systems and the piloting expert system is critical.

ciation and promulgated as "NEMA 0183." It might be useful to *develop more complete standards for NEMA 0183 in order to facilitate linkages among a greater number of shipboard systems.* In addition, *NEMA 0183 or a similar standard could be used for interfacing bridge equipment, and a standard similar to NEMA 0183 could be developed for interfacing engineering and cargo/ballast systems with IBS.*



Integrated bridge system aboard the *Regal Princess.* (*Sperry Marine, Inc.*)

In addition, international standards regarding standardization of the required alarms, displays, and controls to be located on the bridge of vessels equipped with ISCS could be developed for use by classification societies. Rules also could be developed for the functional layout and design of bridges of ISCS vessels, to ensure the crew's access, from a single control station, to all required controls and information, including visual and audible lookout posts.

Taking a broader perspective, traditional maritime operating practices may have to change if the full benefits of integrated technologies are to be realized. Many laws and regulations going back to the 1800s—those dealing with watch-standing, manning, titles, and so on—preclude the most effective use of integrated technologies. An example is the requirement for a 12-channel GPS in an ADS system, discussed later in this chapter. To remedy that problem, *ADS could be redefined to yield a performance-based minimum specification, which might provide for equal or better performance than the current system at lower cost, while also allowing for improvements*. Appropriate DGPS receiver standards to be used as reference for planning and development of new radionavigation systems are expected to be completed by the Radio Technical Commission for Maritime Services (RTCM) by summer 1994.

Meanwhile, because ADS technology is so costly, up to $50,000 per installation for a large ship, its potential value in increasing efficiency in shipping and reducing risk has not yet been demonstrated. This limitation impedes voluntary user acceptance. *Research and development could be conducted in an effort to simplify the ADS system and possibly yield a more economical package that would find greater acceptance and quicker deployment in the international fleet*. If DGPS becomes mandatory for navigation, then ADS will become more attractive to users. Most vessels would have to be equipped with ADSSE for ADS to become a primary means of surveillance. However, it may still be necessary to use radar to provide more comprehensive surveillance of other vessels, including fishing and recreational vessels, that would not be equipped for ADS but could affect the transits of commercial ships and tugs with tows.

ADSSE, by displaying DGPS-based ADS data on the ship's bridge, could provide a very useful complement to ARPA. Vessel tracks based on DGPS are more accurate and more reliable than are radar tracks, because DGPS is inherently more accurate than radar and is not degraded by clutter or weather effects. Further, the accuracy of DGPS is enhanced when the system is used to gauge the distance between vessels. This is due to the cancellation of any common errors in the differential corrections. One concept for the application of ADS as a complement to ARPA involves a vessel receiving many ADS broadcasts from other vessels (by monitoring the ADS communications channel) but tracking and displaying only those targets within a selected range. Used in that manner, ADS shipborne equipment could reduce substantially the uncertainty and communications workload now facing the mariner in determining the intentions of approaching or passing ships. If integrated with ARPA or used as input to an integrated navigation system, ADS shipborne equipment could provide faster and more accurate solutions for collision avoidance than are available now.

As a near-term substitute for ADS and ECDIS, *a PCNS system could be developed*. The system could provide a means of coping with vessels that do not meet U.S. safety requirements concerning DGPS and ADS capabilities. The PCNS could offer no benefits until the Coast Guard DGPS network becomes operational. Although it may be possible to use electronic signals from privately operated radio-determination systems, under federal law and regulation only the federal government may operate most radionavigation systems for use in navigation. Although federal regulations permit the Coast Guard to authorize establishment and operation of private aids to navigation, "with the exception of radar beacons (racons) and shore-based radar stations, operation of electronic aids to navigation as private aids will not be authorized" (33 CFR 66.01-1). The lightweight, compact PCNS would be carried aboard by the pilot,[9] perhaps in some

[9] The concept of the pilot bringing portable safety equipment on board is not new. Some 30 years ago, VHF radios were brought on board by pilots, and the ship owners were charged for this service. Pilots continue to carry personal VHF radios as a standard practice.

type of backpack. The system could be purchased by pilot associations and its use underwritten through a pilotage charge. The PCNS prototypes could be developed for use in pilotage areas where equipment funding and Coast Guard research and development assistance were available.

Apart from supplementing whatever navigation technology may be available on older ships, the PCNS system could ensure that pilots have a familiar system to work with. As noted earlier, pilots are confronted with a bewildering array of shipboard technologies and permutations of equipment configurations. Further, new equipment does not necessarily eliminate the need for or use of the old. As the traditional maritime countries adopt new technology, the ships being replaced, rather than being scrapped, usually are sold to other (often smaller and foreign) operators.[10] Meanwhile, the new ships compete, creating a continuous need for new cost-saving technology, and the world fleet is divided into an increasing number of technological tiers. Because of the lack of standardization, the demands on pilots would not be relieved even if all ships were equipped only with advanced technologies. Possible approaches to alleviating this problem include enhanced pilot training, development of operational guidelines or standards for equipment use, pilot-carried navigation equipment, and provision of a pilot specially trained in navigation technology to provide and ensure adequate support for the lead pilot.

Piloting expert systems, meanwhile, show promise for providing the reductions in work load, information overload, and risk that would facilitate acceptance of ISCS. As a component of an IBS, a piloting expert system could enhance safety by providing a double check on pilot actions or sounding danger alerts. Preliminary assessment of such piloting expert systems through ship bridge simulation suggests that bridge team performance, particularly decision-making, can be significantly improved (Grabowski, 1989). This may be the best use of expert systems. Stand-alone systems force human users to integrate a variety of disparate information available on the bridge, thus defeating the purpose of a decision aid designed to relieve information overload.

Because expert systems are likely to be concentrated on ships with advanced bridge designs, *continued research and development in expert systems could emphasize decision support for IBS and ISCS operations* . In any case, use of piloting expert systems on old ships would require a retrofit with real-time local area networks, because such ships lack the necessary computing and communications infrastructure. [11] In addition, *expert systems could be developed specifi*

[10] This means that the increased supply of new ships is not matched by a corresponding decrease in the supply of old ships. The sheer number of ships poses increased operational and environmental risks, not to mention additional risk if operational systems are not adequately maintained.

[11] It is likely to be easier to introduce advanced technologies aboard new rather than existing vessels. Installing new technology on older vessels may prove too difficult or expensive depending

cally for piloting complex and heavily traveled waterways, where there is an immediate need for reduction of operational risk. Knowledge bases for each port could be developed and tested as well. Finally, *continued development of expert systems could focus on improving compatibility and integration with PCNS, IBS, or ISCS computer operating systems*. Given adequate additional research and development, expert systems could fill gaps in integrated systems.

The use of expert systems raises an issue of great importance to pilots—whether a human expert would be needed at all on a ship so equipped. But there is no guarantee that an expert system will perform or be used effectively. Furthermore, an expert system may not have all the *local* information necessary for safe navigation, and the system may not be linked to sensors capable of detecting vessel behavior relative to prevailing environmental conditions.[12] Therefore, a marine pilot would continue to serve the safety interests of the port-state by providing a double check on the expert system as well as knowledge of and responses to local conditions. Marine pilots also could help validate the performance of expert systems; this assistance may be essential for system credibility in any case.[13] Eventually, the introduction of expert systems may alter the role of marine pilots in some way.

The effect of advanced technology on bridge manning is also a concern. The introduction of new technology requires new operator skills that do not necessarily replace the more traditional skill requirements. Further, new potential for human error may be introduced.

At times it may still be necessary for someone to steer the ship, such as when transiting a narrow canal or congested waterway where frequent maneuvering is required to remain in the channel or to accommodate other traffic. If there is no longer a dedicated helmsman, hand steering requires some other

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on the bridge configuration of the vessel, its engineering systems, cost of modifications, and so forth. Thus, some advanced technologies may or may not be suitable for retrofit. Although an integrated bridge may not be feasible on an older ship, some of the principal benefits such as real-time position displays can be gained through the installation of ECDIS.

[12] Ideally, all published nautical information and other knowledge needed by the conning officer (or pilot) to maneuver the ship safely could be displayed and controlled at one station on the bridge. However, locally specific data and knowledge are required for which published data are not available, or that require interpretation or response that are beyond the capabilities of existing sensors and computer-aided decision aids. For example, understanding of the hydrodynamic interactions between a vessel and channel bathymetry, and the collection of physical data needed to predict their effects, have been identified as research needs in using marine simulation for waterway design (NRC, 1992a). The difficulties inherent in detecting hydrodynamic effects and maneuvering in response are compounded by the lack of real-time environmental data, the presence of other traffic, and the many other factors that affect vessel behavior (see Chapter 4).

[13] The threat represented by expert systems and other artificial-intelligence tools often can be mitigated by thoughtful and gradual introduction of the technology, the extension of benefits to affected workers (that is, crews and pilots), substantial theoretical and hands-on training, and phased introduction of the systems to oceangoing fleets.

ship's officer or crewmember to undertake this task, in some cases abandoning other duties. If hand steering and response to voice commands from a pilot are not practiced regularly, the potential for human error and impaired task performance is increased. An IBS may be configured to support hand steering, but placing the mate (or master) in this role might increase task loading. Another view is that task loading might actually decrease if steering becomes an automated function, relieving the watch officer or conning officer from having to monitor the helmsman's performance. However, the person steering the vessel would not be able to leave the steering position without a relief or engaging an autopilot. For example, it may be necessary to obtain a better view of an overtaking vessel from the bridge wing. There would also still be the potential for human error involving communications between a pilot and whomever is steering the vessel. Conceivably, the pilot could also take the helm, although how such action would affect the full range of piloting tasks is not clear.

There is a significant difference between a "one-person bridge" and "one-person control." In the former, only one person would be on the bridge during operations. In the latter, direct control is exercised by one individual but others are on the bridge. One-person control is practiced aboard passenger ferries in the Baltic; typically, the master and an additional mate are on the bridge during transits of the most difficult sections of the pilot routes (Herberger et al., 1991). Monitoring and cross-checking practiced as a matter of good seamanship in traditional ship bridge setting must be accomplished through technological means to offset the potential for "single-person error."

Options for Long-Term Development

To improve the accuracy of onboard or shoreside systems for surveillance and collision avoidance, *one or more international radio frequencies could be dedicated to transmission of data among ships and between ships and shore stations*, and *a more efficient standard data protocol (compared with today's standards) could be developed for transmitting data regarding a ship's identity, position, speed, and course*. And to ensure compatibility of integrated surveillance systems among ships of various flags and the port facilities of different nations, *IMO could develop an international standard for ADS*.

To determine the relative risk reductions provided by nontraditional bridge operations, *the Coast Guard or MARAD could commission a quantitative, comparative risk assessment of traditional, ECDIS, IBS, and ISCS operations*. Cost–benefit analyses and risk assessments could be important tools for maximizing return on investment; at present, substantial sums are being spent on high-cost solutions to navigation problems that mitigate consequences (for example, double-hulled tank vessels to mitigate oil spills *after* an accident has occurred) rather than on before-the-fact preventative measures that may be more cost-effective or of greater overall benefit. To ensure that all technical issues are considered, the comparative study would need to include participation by vessel operators and relevant equipment manufacturers. The IBS already has been identified as an important research topic (Box 6-6). Determining the appropriate role of marine pilots with respect to the pilotage of ships with an IBS is also an important consideration that merits attention (Box 6-7).

Meanwhile, *regulations could be developed to allow nontraditional bridge team organization for ships with IBS meeting acceptable standards.* In particular, these regulations could recognize the ability of the watch officer to operate the ship's controls without assistance from a separate helmsman and the capability of ECDIS to maintain a plot of the ship's position (Roeber, 1992).

Finally, *manning laws and regulations could be reviewed and amended to*

BOX 6-6 INTEGRATED BRIDGE SYSTEMS (IBS)

The integrated bridge was identified as one of several priority research topics at the Ship Operations Cooperative Program Workshop convened in October 1992. A project was identified to implement technology that can improve operational efficiency and safety. The cooperative, which is sponsored by the Maritime Administration, is considering a project that would assess the existing and future technologies of integrated bridges, expert systems, and bridge equipment (including ECDIS). This project would address risk assessment, life cycle analysis, and implementation schemes for various integrated bridges. Other planned projects include the development of an optimized model for bridge operations and standards for navigation, communications, steering, and expert systems (John Dumbleton, MARAD, personal communication, July 21, 1993).

With integrated bridge systems for large ships, the deep sea mariner joins the ranks of operators in the towing industry, in small commercial vessel operations, and other forms of transportation, who steer their own units and are not dependent on others to ensure error-free control. They will be dependent, however, upon individual work practices, ergonomic design, and technical systems to monitor and cross-check to detect single-operator error and alert the operator to needed corrective actions. These developments certainly will spark debate about how to adapt the myriad laws and regulations that have evolved around the traditional mode of bridge operation. Indeed, the debate has begun, with the trials of "one-man bridges" (with the watch officer serving as the sole lookout at night) that have been authorized by IMO. Several countries, including the United States, have denied trial vessels access to their territorial waters.

Regardless of the outcome of these trials, more and more future ships will be built with IBS. The technology might be too expensive to retrofit. One-person bridge operation, if found viable, would provide an economic incentive that would hasten adoption of IBS technology. However, change to IBS, even if it were mandated, would be gradual.

BOX 6-7 MARINE PILOT USE OF INTEGRATED BRIDGE SYSTEMS

Marine pilots, by nature of their profession, must be adaptable to changes in operating conditions, including technology. If integrated bridge systems are ergonomically designed to be user friendly, and if means are established for pilots to become familiar with these systems and their capabilities before having to rely on them while piloting, then marine pilots would be expected to experience no particular difficulty in using these systems.

A proliferation of system control configurations could exacerbate the problems now encountered with a lack of configuration standards for ARPA. Understanding the electronic charting system display, for example, is generally self-explanatory after experience on well-designed systems. It is likely that marine pilots will become proficient in operating the controls of models that ultimately dominate the market. During the extended period over which IBS are introduced and for less frequently encountered configurations, the pilot will need to be briefed by the master or watch officer on basic system controls, or more likely, will find it necessary to rely on the watch officer to set up and manipulate display systems at the pilot's request.

Assuming that the pilot can operate a system with all the instrumentation centered around a single workstation, when the pilot leaves that station, access to the information displayed could be seriously constrained unless additional displays are provided at strategic locations. The pilot is then placed in the position of attempting to conn the vessel with considerably less input from bridge instrumentation than would normally be available or visible to the pilot on a conventional bridge. Choosing between visually sighting a small boat or buoy disappearing under the bow or alongside (common occurrence in narrow channels) or abandoning the ability to monitor and control the ship's progress is a troublesome decision that could easily affect the safety of the passage. The decrease in mobility encouraged by central workstations without the provision of additional displays can also lead to non-detection of approaching vessels.

The integration of the marine pilot into IBS operations could be enhanced by attention to organizational and technological designs that permit flexibility in exercising direction and control over the vessel coupled with a means to monitor system information away from the single or pilot/copilot workstation and workstation design that permits access by more than one person. This would need to be accompanied by adequate shipboard organization and professional discipline among all members of the ship's bridge team.

facilitate training and licensing of a single class of watch officer. These officers would be responsible for all operating functions aboard ships equipped with ISCS meeting acceptable standards. At the same time, *maritime academies could revise curricula to train for such a position*. In devising such training programs, it is important to remember that new technology demands new skills but may not obviate the need for traditional skills such as those of the marine pilot, and, furthermore, that technological advances may introduce new potential for human error. Automated systems may produce an *economic* benefit by providing for reductions in crew size, but *safety* benefits accrue only to the degree that proper use of advanced technology results in no increase in the probability of undesirable events (Kristiansen et al., 1989).

Weather and Environment Monitoring

Information about the weather and the operating environment is essential for safe navigation. Mariners need accurate forecasts to avoid potentially damaging storms and to determine tides and currents that will allow a vessel to enter port safely. To effectively maneuver a ship, they need real-time information about the speed and direction of the wind and currents, coupled with an understanding of how the forces exerted on the ship are expected to change within the confines of a harbor. The local pilot, after boarding, is usually the best source for port-specific information, but the ship also must have significant onboard capability. Mature technologies for monitoring and predicting environmental conditions include the recording barometer; anemometer and wind-direction instruments; tide and current tables; and weather telefacsimile receivers, programmed to receive forecasts and weather maps.

Several new technologies are being tested or introduced that show great promise for reducing the risks posed by the uncertainties of the marine environment. These include electronic tide predictors (Mays, 1992); the PORTS system noted earlier (briefly described in Appendix G), now installed in Tampa, Florida (Appell et al., 1991; Bethem and Frey, 1991; Frey, 1991); weather routing services, which provide forecasts as well as recommendations for changes in voyage plans to avoid severe weather; and hull-stress monitoring systems.

Options for Incremental Improvements

The availability of ECDIS will provide an opportunity to apply new technology for real-time monitoring of sea conditions. At present, PORTS data are transmitted by radio on an hourly basis. *Real-time radio transmission of PORTS data and modification of ECDIS could enable the use of real-time data for ECDIS display of actual water levels and wind and current vectors*. In addition, systems for monitoring hull stress could be enhanced by *development of highly reliable hull stress-sensors and methods for mounting them that could withstand the marine environment*.

Options for Long-Term Development

The PORTS system could be extended to all major U.S. harbors, concentrating first on those where the need for real-time tide, current, and weather data is determined, by consultation with the marine industry, to be the greatest. Al though the PORTS system has been very well received by its marine users, NOAA reports that agency resources are not available for long-term operation, much less for expansion of the capability to other ports. The agency has suggested that revenues collected from the marine transportation industry and maintained in the Harbor Maintenance Trust Fund (in excess of funds needed for channel maintenance) might be an appropriate source of funding for continuation and expansion of the PORTS program.

Docking Evolutions

Docking large vessels is a time-consuming and potentially hazardous operation. The velocity and position of the ship as it approaches the dock must be controlled carefully to prevent damage to the dock or the ship. This maneuvering requires skill and experience; control of the ship's engine, rudder, and bow thruster (if available) must be coordinated accurately with the forces provided by one or more tug boats to achieve proper velocities in an environment of wind and currents.

Little research and development has been conducted in recent years related to docking technology, although two types of technologies have been introduced: dual-axis docking Doppler systems and constant tension winches. Constant tension winches are very useful during docking evolutions. They are designed to maintain constant tension on the wire ropes used to winch or hold a ship alongside a pier. The tension can be set to avoid the parting of these ropes that would endanger linehandlers on the ship and the pier and that would complicate docking. This feature also allows the ship to be warped along the pier to attain the desired position.

Tests are being conducted with automated docking systems. Real-time precision navigation systems also can be employed in such systems. For example, installation of DGPS antennas on both the bow and stern could be used to precisely monitor both the forward and lateral movement of the vessel during docking maneuvers.

Options for Incremental Improvements

Automated docking systems are a promising new technology. *Ongoing research and development could be accelerated to allow early implementation of automated docking systems*, which could be helpful in certain U.S. ports. Adequate control and positioning technology is available, but additional research and development is needed to produce autonomous systems. Such systems are under development in a number of countries as part of "intelligent ship" programs. The most notable advances have been made by the Japanese, who in 1990 conducted an evaluation of their automatic berthing and unberthing system aboard the experimental ship *Shoji Maru*.[14] Experiments with the Japanese system showed that smooth and accurate transitions to and from berth were possible, that the orders generated by the system mimicked those expected from an experienced captain and docking master, and that the approaching speed of the ship was reasonable and safe. Although autonomous systems have yet to be deployed, a number of experimental docking-assist systems are undergoing evaluation aboard operating vessels.

Winches require heavy maintenance because of the harsh environment of the weather decks on which they are located. It might be useful to *develop more-reliable and less-maintenance-intensive winch-control system* to ensure their availability for use during docking evolutions.

Options for Long-Term Development

No specific options for long-term development were identified.

TECHNOLOGICAL CHANGE

How Marine Navigation Technology is Adopted

Historically, advances in marine navigation technology have been driven largely by military needs and considerations (such as radar in World War II), and to some degree, by marine-related missions of federal agencies (e.g., the aids to navigation maintained by the Coast Guard). Now, however, certain advanced navigation equipment can be applied as an integral part of bridge design to gain an economic benefit. Advances in electronics and space technology permit automation and integration of navigation tasks such as fixing and displaying the ship's position. Automation facilitates reduction in manning, a change in practice pursued by the shipping industry to reduce operating costs; automation also can be applied to expedite the work of the remaining crew, a useful feature on complicated modern ships. The trend is for ships to become more automated overall (NRC, 1990a). [15]

Change generally has evolved slowly in the marine industry, in part because most technology has not been developed or regulated centrally. However, economic competition has increased the pace of technological change. History shows

[14] The Japanese Intelligent Ship Project is a joint research program organized and managed by seven shipbuilding companies under the Shipbuilding Research Association of Japan. The ship is owned by Tokyo University of Mercantile Marine.

[15] Technology exists for remote and centralized monitoring and control of the engine room; water and fuel flows; and such functions as navigation, loading and unloading, distribution of ballast for stability, maintenance, inventory of parts and stores, and even administration (Ohmes and Robinson, 1987).

that shipping companies adopt new technologies if their actual use *substantially* reduces operational risk and uncertainty (and thereby economic risk). The speed of adoption depends on availability and reliability of the technology, its proven value through demonstrated effective application, and its cost. Another factor affecting application is that use of advanced technologies involves a complex of changes related to design, performance, and reliability, some of which may *increase* risks (Aranow, 1984; NRC, 1991b; Reason, 1992). Other important factors affecting technology acceptance and application are impediments to innovation and application of technology embodied in laws, regulations, and legal precedents.

Two examples of adopted technologies, albeit motivated by official mandates, are bridge-to-bridge communications and radar. Marine pilots now consider VHF radio and radar fundamental to piloting practice and have been instrumental in establishing their near-universal application. This is a legal as well as a practical choice. If a pilot fails to use available proven equipment and an accident occurs, then a defense of prudent seamanship becomes vincible in disciplinary proceedings. This concern may be applicable to newer technologies if their use becomes "fundamental" to basic navigation practices.

Marine Transportation Companies and Technological Change

The key force driving the installation and use of navigation technology by marine transportation companies is economics, although the economic contribution of safety improvements and public interests in safety may in some cases be strongly considered in decision-making. If the economic benefits of a technology are not obvious—and they may not be—then vessel owners are not inclined to buy it without an official mandate that provides incentives or requirements to do so. The economic influence in a highly competitive industry is so powerful that it could work against a safety scheme based on universal voluntary application of specific technologies. Increases in operating costs (including any associated with mandated technology) that affect financial well-being could lead to a shakeout in ship routing, fleet composition, or both. This result would determine whether there would be a net benefit in economics or safety. Nevertheless, a small but growing number of operating companies have made considerable investments in high-technology integrated navigation systems, for example, to facilitate uninterrupted passenger service or to reduce operational (and economic) risk in tanker or freight operations (Herberger et al., 1991).

Mariners and Technological Change

Dependent as it is on evolving economic, safety, and legal pressures, technology acceptance can be an arduous, piecemeal process. Mariners are often ambivalent about change, and they tend to cling to proven traditional methods until convinced that a new technology works. As an illustration, testimony solicited from marine pilots indicates that their work remains more an art than a science. Some feel that "more sophisticated technologies do not contribute much, and may only serve to increase the load on the pilot" (Ramaswamy and Grabowski, 1992). Yet many pilots have become ardent advocates of technologies such as radar, and especially over the last several years the use of marine simulation for continuing professional development. Likewise, if emerging high-technology navigation systems can be demonstrated to be significantly helpful in their work, marine pilots are likely to become ardent supporters of universal use of such technologies. That is, they will unless operating companies attempt to substitute advanced technology for pilotage services, thereby reducing pilotage costs and threatening pilot livelihood.

Although some marine pilots have promoted the use of advanced navigation technology, for example, the use of bridge-to-bridge radiotelephone (USCG, 1972), pilots in the past infrequently were brought in at the "proof of concept" stage of technology development, with the notable exceptions of computer-based marine simulation for channel design, and more recently, in developing some VTS systems (Maio et al., 1991; NRC, 1992a). Perhaps pilots were not called on more for the development of navigation technologies, because visual piloting is still relied on to a significant extent in confined waters. But public expectations for the safety of vessel operations are changing, and there are unmet needs for all-weather, precision positioning capabilities. However, marine pilot expert knowledge of shiphandling and confined water operations is a resource that could be better used in the research and development of advanced systems, to help ensure that these systems will achieve their full potential in reducing risk in pilotage waters. Further, marine pilots are in a unique position to assist in validating newly introduced technologies and to provide leadership in their application (such as for pilot-operated VTS or VTS-like systems).

What is occurring in marine transportation, then, is a convergence of old and new navigation practices. The traditional and trusted piloting methods, which rely heavily on visual observation (of varying acuity), use of radio and radar, and the application of expert local knowledge, are being weighed against high-technology solutions that offer real-time information and support for precision navigation and decision-making—but that have yet to inspire confidence and trust.

This quandary contrasts with the situation in aviation, where new systems are tested by central authorities, and U.S. industry routinely complies with the mandated schedule for installing and retrofitting the devices on all aircraft (Gold, 1990a). ICAO[16] has broad powers to promulgate standards and practices for new

[16] The ICAO is more active and more adequately funded than the IMO, which is funded in accordance with the respective tonnages of flag states. The IMO funding scheme is a problem because over 20 percent of the world's tonnage is registered in Liberia and Panama; neither nation has contributed to IMO activities in recent years due to internal financial difficulties in each country (CHA, 1990).

systems. The development and implementation process is said by some to unfold relatively quickly, although this depends on the point of comparison. What is more, considering the total capital and operating costs of aircraft, measures which enhance safety and performance were routinely considered as cost-effective (Gold, 1990a). This receptiveness appears to have changed somewhat as a result of less favorable economic conditions in the aviation industry. Nevertheless, the well-established strong organizational structure and institutional processes that facilitate the introduction of technology remain in place.

The acceptance by U.S. airlines of the Microwave Landing System (MLS) provides a cogent example of more recent conditions. MLS was developed and shepherded through ICAO by the United States as the landing system for the next century. However, with the advent of satellite navigation, the airlines have convinced the Federal Aviation Administration to establish a vigorous development program to determine the feasibility of DGPS application to precision approaches, including Category III approaches (zero ceiling limitation). This user initiative is based on economic benefits, where airlines believe that the flexibility of satellite navigation, with respect to coverage at all airports worldwide, user preferred routes, single system for all phases of navigation, and application to automatic dependent surveillance, will lead to substantial costs savings in their operations (RTCA, 1992).

Pitfalls of the Application Process: Some Examples

The introduction of new navigation technologies has been met more by operator reluctance to give up traditional systems than by forward-looking enthusiasm. The absence of wholehearted support has created a number of problems concerning advanced technologies, including lack of standardized equipment, a shortage of validation methodologies, regulatory standards that constrain either optimal usage of technology or its further development (or both), requirements for specialized training, and considerable reliance on traditional practices even when using advanced systems. Following are specific examples.

Multiple Equipment Configurations and Regulatory Restrictions

Two problems—multiple configurations and regulatory restrictions—are illustrated by ARPA. Marine pilots responding to a committee inquiry complained about the lack of standardized ARPA consoles, a frequent cause of pilot difficulty in using this equipment effectively (Ramaswamy and Grabowski, 1992). Such difficulty poses a safety risk if bridge team support to the pilot in making effective use of ARPA is inadequate, perhaps even canceling out the collision avoidance safety benefit ARPA is supposed to provide (Ramaswamy and Grabowski, 1992; Zabrocky, 1992). Further, ARPA's capabilities are specified—and limited—by regulations (33 CFR 164.38). ARPA's plane of reference must be the water plane; that is, speed data should be obtained through the water signal. But water-speed instruments—once the only technologies available for determining speed—are neither very accurate nor very reliable. Today, navigation equipment using DGPS signals can measure speed very accurately over ground. This data cannot be used with ARPA, however, because regulations do not provide for measurements by means other than water speed instruments. The result is that mariners, frequently unable to obtain an adequate water signal, often enter speed information manually, sometimes forgetting to change it later. Resulting ARPA solutions are degraded in relation to the error introduced, increasing operational risk.

Regulations addressing technology application can either foster or impede research and development, depending on how they are written. For example, a 12-channel GPS receiver is required by the Coast Guard for the ADS/VTS system for tank vessels over 20,000 deadweight tons in Prince William Sound (33 CFR 161.376). As written, the regulation does not provide adaptive flexibility or include provisions or incentives to motivate further improvements in positioning accuracy or system integrity. But if the wording were changed to specify a minimum integrity comparable with that provided by the 12-channel GPS receiver, the regulation still would result in the near-term adoption of this equipment while also providing latitude for subsequent technological innovation.

Performance Objectives and Assessments

Another concern is that construction and performance standards are not available to guide the introduction of high-technology systems or to minimize the unconstrained proliferation of different configurations and features. Advanced technologies are becoming more reliant on software and therefore can be modified *very* rapidly—much more rapidly than can traditional hardware-based technologies—for the purposes of correcting deficiencies and improving capabilities (Buxton and Hornsby, 1992). However, the range of possible permutations and the speed at which they can be made and introduced has the potential to exacerbate the difficulty that mariners, especially pilots, have in building and maintaining familiarity with high-technology navigation systems. These difficulties are compounded, because only a few standardized methods have been developed for validating software short of extensive field trials. Validation is a current research topic in the software engineering community and vessel classification societies (Buxton and Hornsby, 1992; MacIennan and Shaw, 1992; Singpurwalla and Wilson, 1993). Such tests are the principal method for determining logic or programming flaws in software and evaluating actual system performance relative to designed capabilities. For example, before new or updated personal computer software is introduced for sale, in addition to bench tests, special field trials, referred to as "beta" tests, are conducted by individuals selected to challenge software capabilities and performance. Many, but not necessarily all, "bugs" in the software are identified for subsequent correction.

Generally, software can be tested without creating any physical danger. However, this is not the case for field testing either software or hardware in marine systems. It is difficult if not impossible to stress a technology sufficiently to see if it works, in either a port-and-waterways operating environment or river system, without exposing the vessel serving as the testbed to some physical dangers. These dangers become more pronounced as the pilotage waters or traffic situation become more challenging.

For most potential applications, it does not appear economically feasible to employ large vessels in commercial service as dedicated testbeds, although some limited trials may be feasible. Further, operational risk in conducting such tests might be significant. Although small, maneuverable vessels could be employed as testbed platforms for beta-like tests, even this is costly, not entirely without risks, and it appears to the committee, not frequently done. Whether or how well the results of such testing would transfer to large platforms of far different design, outfitting, and manning has not been ascertained.

Simulation technology has been used in a few cases to evaluate a new technology (Grabowski and Wallace, 1993; Schuffel et al., 1989) or to test technology utilization (Akerstrom-Hoffman et al., 1993; Alexander and Klingler, 1992; Gonin et al., 1993; Smith, 1993). Simulation offers a controlled environment absent of physical dangers to the participants, and the ability to test the technology under operating conditions too dangerous for field tests. Although far less costly than field tests for the same level of empirical observation, the cost and time-intensive nature of simulation, and the need to install and effectively integrate the technology into the simulation, have impeded widespread adoption of this technology for this purpose.

Another testing approach is to combine use of marine simulation and afloat testbeds. This is the approach employed in the U.S. ECDIS Testbed Project, a multifaceted government–industry demonstration, test, and evaluation project. The project is supporting the development of international performance standards for ECDIS by the IMO. The U.S. researchers are testing the capability and limitations of prototype ECDIS systems; evaluating the adequacy of proposed international ECDIS design and performance standards; and examining the incorporation of the human–machine interface into ECDIS design, operation, and performance (Alexander and Black, 1993; Alexander and Klingler, 1992; Gonin, 1993; Marine Log, 1992). Controlled experiments and tests that could not be readily performed at sea were conducted using marine simulation (Akerstrom-Hoffman et al., 1993; Alexander and Klingler, 1992; Gonin et al., 1993; Smith, 1993). Afloat tests have employed a ferry boat, a 180-foot Coast Guard buoy tender as the testbed, and a maritime academy training vessel. Although these vessels did not exactly represent large commercial ships in terms of bridge configurations, maneuvering characteristics, and manning levels, the tests that were conducted yielded valuable insight for the ECDIS testbed project (Gonin, 1993; Gonin and Crowell, 1992).

Ultimately, it appears that a technology must be field-tested aboard the precise class or type of vessel for which application is intended to determine effectiveness for that type of platform in the range of operating conditions that will be experienced. Field trials also appear to be needed for each individual installation, because of differences among vessels, even those of the same type or class (see Chapter 4). In select cases, it may be possible to obtain a broad-base of experience with a new technology by applying it on regular routes, with regular bridge team personnel, over a wide range of operating conditions and for an extended period. This approach was used to evaluate and build trust and confidence in integrated bridge systems aboard large passenger ferries in the Baltic (Herberger et al., 1991.) However, little if any formal performance monitoring of applied technologies seems to be the norm. (Previous NRC assessments have consistently identified a need for more systematic assessment of safety needs and performance of safety measures and safety data to support such assessments [NRC, 1990a, 1991a].) There appears to the committee to be a general reliance on informal evaluation by shipboard personnel; their operational insight is essential, but few mariners are prepared to evaluate technical performance scientifically, especially of software, that requires a programmer's critique.

As a general practice, a new technical system is usually installed aboard a vessel, and experience is gained with it through actual operations. A danger in this approach is that mariners might become prematurely confident in the new technology through its continued use at sea rather than through experience with it in pilotage waters. Yet, it would be imprudent to rely solely on a new technology for navigation in pilotage waters without establishing a solid basis for trusting it. Therefore, despite the apparent potential of emerging technology to improve navigation, a conservative approach to operational acceptance is justified, especially with regard to the software-based technology. At the same time, the desirability of reducing operational, economic, and environmental risk argue for prudent acceleration of technology introduction, validation, and acceptance.

Performance Objectives vs. Equipment Mandates

Considering the pitfalls and uncertainties that may be encountered in introducing new technology, it may be advisable to develop *baseline* standards that emphasize *performance objectives* rather than mandating specific equipment. Performance-based standards leave room for flexibility in exceeding the requirements or meeting them in new ways, thereby allowing users to respond to dynamic changes in needs and to employ technological advances as they become available. This approach has taken hold in civil aviation, where the trend is toward specifying required navigation performance rather than the carriage of designated equipment (RTCA, 1992). The user thus may choose the navigation configuration that satisfies both legal requirements and individual preferences. Of course, this advantage could be lost if, to achieve a specified level of performance, a navigator had no option but to use one particular type of equipment.

Ensuring Pilot and Watch Officer Proficiency

Among the new problems posed by advanced technologies are the subtle difficulties involved in their practical use (Perrow, 1984). The introduction of radar into the fleets provides a useful example. A number of marine casualties suggested that the watch officer or pilot sometimes became so engaged in operating the radar that awareness of the larger navigational picture was lost, resulting in decisions that contributed to or caused collisions. Marine simulation research determined that watch officers sometimes became more absorbed with a problem when using radar than with visual sighting or when computer-aided decision aids were available (Aranow, 1984). This phenomenon became known as "radar-assisted collisions" (Hebden, 1990; NTSB, 1972; Wenk, 1986). The term is also used to refer to collisions associated with pushing the limits of safe operations by relying on radar during periods of reduced visibility. Radar enables maneuvers or speeds that would not normally be attempted if radar were not available, but these actions may not be prudent.

Similar problems are possible with new navigation technologies such as integrated radar and electronic charting systems if they are not used carefully. What is more, if masters, other members of bridge teams, and marine pilots have to become familiar with new systems through on-the-job experience, they may find it difficult, if not impossible, to learn effectively without at the same time compromising the integrity of piloting or watchkeeping. To minimize such a possibility, training requirements for new technologies would need to be determined and, insofar as is practical, training provided prior to using the technology. Alternatively, special provisions could be made to ensure that proficiency in the use of the new technology was established without compromising safety and performance. This level of training is employed routinely in commercial aviation.

Technology-Induced Changes to Pilotage

The time-honored methods of piloting, recruitment, and on-the-job professional development may be challenged by inexorable technological changes. With the emergence of sophisticated technologies and new bridge configurations, marine pilots find themselves and their profession under increasing pressure to update their practices to make use of these new capabilities.

In the past, marine pilots adapted to such changes as new technology as it entered the commercial fleet and appeared in their service area. This was an adequate approach, because the slow pace of change provided sufficient time for pilots to become familiar with new systems. Likewise, traditional pilotage systems and pilot development programs were adequate to meet professional-development needs. However, the existing systems and programs are not structured to develop the needed technical skills in a rapidly changing operating environment (see Chapters 1 through 3). Associated training issues are discussed in Chapter 7 and Appendix F.

Chances are that marine pilots will find it necessary to adapt to changing technologies to satisfy the professional expectations of operating companies, masters, and public authorities concerned with operational and environmental safety. How quickly this need will develop is not certain; given the swiftness of technological advances and the lack of universal, continuing professional development programs, it could be soon.

7

A Human Systems Perspective on Marine Navigation and Piloting

SUMMARY

Lapses in human performance have contributed to most marine accidents, but the understanding of human systems needed to guide improvements in the marine navigation and piloting system is not well-developed. The marine navigation and piloting system and its subsystems as they are organized and operated, particularly the traditional shipboard structure for command, control, communications, and information (C^3I), induces rather than reduces the potential for human error. Recent innovations in the marine navigation and piloting system to improve C^3I include changes in bridge organization such as bridge teams, the one-person bridge, and the pilot-copilot bridge configurations. Another important development is the application of marine simulation for professional development. To further reduce risk, a variety of issues must be addressed in the areas of C^3I: error reduction, reaction time, automation of error-prone functions, and rationalization of tasks.

Human systems in the marine navigation and piloting system could be improved through changes in structure, decision-making, communication, and culture. The system could be restructured to better integrate interdependent decision-making among its various components. Decision-making processes within organizations could be made more flexible to facilitate decision-making at the organizational levels closest to available information about the decision and its implementation. Communications processes could be improved with regard to the development of interpersonal trust among personnel in all segments of the marine navigation and piloting system. Finally, appropriate cultural changes could be nurtured to improve attentiveness to safety considerations.

The Coast Guard has initiated an improved data collection methodology for human systems information and an integrated human factors research and development program to develop an empirical technical basis for technological advances and marine safety regulations. Modest research and development of technical systems to support bridge team and watch officer performance continues to be undertaken by the Maritime Administration as well.

INTRODUCTION

Although human performance is recognized as a contributing factor in most marine accidents, the understanding of human systems (Box 7-1) and human–machine interactions that are needed to guide improvements in human performance as this pertains to marine navigation and piloting is not well-developed (Box 7-2). Further, the understanding of organizational processes that contribute to unsafe operating practices in the system is very limited.

This chapter examines human systems and organizational processes as they relate to the marine navigation and piloting system, and example of a large-scale sociotechnical system. Interactions of the system's major components introduced in Chapter 1—navigation and piloting tasks, human systems, organizational culture and structure, and technology (Figure 1-1)—are analyzed with respect to human, organizational, and environmental imperatives. In keeping with the overall focus of the report, emphasis is placed on navigation and piloting tasks.

The opening section presents an organizational view of the marine navigation and piloting system, especially the adequacy of communication in its management. The heart of the chapter addresses navigation and piloting from a broader perspective by examining environmental and internal organizational contexts in which piloting and navigation take place. Human–machine interactions (also referred to as the man–machine interface) are also addressed.

BOX 7-1 SOME TERMS USED IN THIS REPORT

HUMAN FACTORS An area of ergonomics that considers human-machine interfaces. An element within human systems.

HUMAN SYSTEMS Large-scale systems, usually somewhat geographically dispersed, that require interdependent decision-making and action in order to function successfully as a whole. In the context of marine navigation and piloting, human interactions and decision-making on board each vessel and with shore-based marine traffic regulators is included.

BOX 7-2 HUMAN SYSTEMS LITERATURE

Human systems literature for the marine navigation and piloting system was principally derived from marine simulation research covering topics such as the use of simulation in marine training and licensing; professional development and performance of helmsmen, cadets, mates, masters, and pilots; examination of specific operating conditions and collision avoidance technologies relative to human performance; examination of piloted controllability in restricted waterways; and the effects of human factors on watchstanding effectiveness. Much of the literature is over a decade old, and fundamental research is rather moribund worldwide (NRC, 1992a). While this literature is an important resource, the findings have not been updated to reflect current and prospective maritime operating conditions, ship systems, and manning practices.

Significant gaps in human systems literature include:

- impacts on safe and reliable operations of bridge team skill composition and crew size;
- interactions among the shipping company, ship crew, piloting, and VTS (including decision-making, effective use of control systems, training implementation);
- impacts of environmental constraints on shipping companies and ship operations;
- utility of various outcome measures including those assessing performance, reliability, and safety;
- requirements for crews in increasingly technologically sophisticated work environments;
- policy for ports and waterways in which the difference between technology and knowledge about that technology is increasing;
- flexible organizational strategies and structures to respond to growing environmental uncertainty;
- risk in the human aspects of marine management;
- changing relationship of the master and pilot;
- appropriate cultural components of a highly reliable marine systems;
- understanding decision-making processes on ship bridges and the linking of these processes to their external environments (such as VTS, shipping companies);
- needs for checks and balances in the decision-making process;
- needs for truly interconnected distributed decision-making within and across marine systems;
- mechanisms for improving trust within and across various parts of the marine system;
- knowledge requirements within bridge teams and between bridge teams and VTS systems and pilots;
- training needs for various parts of the marine and towing industries;
- relative value of various forms of simulation for different functions and range of mariners; and
- all aspects (from the ability to generalize to cost-effectiveness) of the use of virtual reality training.

AN ORGANIZATIONAL VIEW OF NAVIGATION AND PILOTING SYSTEMS

Systems and subsystems usually are described in terms of their inputs, processes, and outputs (IPO). IPO analysis broadly describes the logic of how systems work. The inputs to and elements of the marine navigation and piloting system include aspects of the operating environment such as markets, regulation, traffic, technology, and shipping company policies and tasks to be performed in this environment. The organizational processes of interest include decision-making, problem solving, communication, conflict resolution, and the evolution of organizational structure and culture. The outputs or the effects of the marine navigation and piloting system include task and job performance; reliability; productivity; health and safety; and operator performance, satisfaction, fatigue, stress, boredom, and retention (in service).

In any systems analysis, there is a danger of optimizing the performance of a single subsystem at the expense of other subsystems or the overall marine navigation and piloting system (that is, suboptimizing). This is a concern and a challenge with regard to the marine navigation and piloting system because the subsystems (such as a port or shipping company) are better understood and managed than the overall large system. Optimizing marine navigation and piloting subsystems also need to consider interactions with external influences such as port management and public policy in order to guide intended effects and to address unintended consequences of change. As an example of a discrete change that could have unintended consequences on the larger system, the U.S. requirement for double hulls on oil tankers might reduce spillage, but this change also means less carrying capacity per ship if double hulls were installed in existing ships, thus creating a need for more ships (Bea and Moore, 1993). Alternately, new vessels could be built with the same cargo carrying capacity. In this case, the vessel would be somewhat larger and depending on the magnitude of change, could in some port areas stress the limits of designed channel capacity if the vessels being replaced were previously operating with small maneuvering clearances in constricted waterways. In other words, the safety benefit could potentially be reduced by an increase in shipping activity or vessel size.

The Operating Environment

Maritime shipping has undergone dramatic changes in recent years. Substantial increases in operating costs in the 1970s and the early 1980s motivated shipping companies to adopt more efficient operating practices. During the late 1980s, interest intensified in reducing operating costs by way of smaller crew numbers (NRC, 1990a). Crew sizes on modern vessels have been reduced significantly from 30 to 40 in the 1960s and 1970s to crews of 20 to 30 today in the United States and 9 to 14 in western Europe, Scandinavia, and Japan (Grove, 1989). U.S. requirements have not permitted reductions as great as those of other flag states, a competitive disadvantage for U.S.-flag ships. At the same time, vessel size has increased and shipboard systems have become more complex. It has often been suggested that crew size reductions may increase the risk of collisions and groundings, although this has not been proved or disproved (NRC, 1990a).

On some vessels, reduction in crew numbers has been extreme. Some large Norwegian vessels sail with only eight to 12 crew members (Kristiansen et al., 1989). The German *Norasia* series carries 16 crew members but is designed to operate with 12 (Gaffney, 1989). The Japanese *Pioneer* ships have crews of 11 (Grove, 1989; Yamanaka and Gaffney, 1988).

Considerable changes also have taken place in the size and structure of marine traffic. Between 1960 and 1980, the number of tankers doubled, and their tonnage increased sevenfold (Kwik, 1986). New types of ships evolved, such as liquified gas and car carriers. With each major development in hull form and superstructure configurations came different maneuvering characteristics. Major changes in vessel size also accentuated the effects of hydrodynamic forces in shallow and confined waters. In addition, numerous structures for oil and gas production have been erected in some coastal waters, complicating marine traffic routing in these areas. As a result of these developments, navigation and piloting tasks in pilotage waters and their approaches have become more difficult and complicated.

Economic competition can also complicate navigation and piloting practices. Vessel scheduling may become volatile depending on how shippers respond to competitive carrier pricing. Intermodal door-to-door pricing means that the carrier chooses the ports and thus has leverage in negotiations; the result is vigorous port competition for the carrier's business. Traffic, therefore, becomes partly a function of carrier pricing, itself a function of intermodal technology. Because pilotage is so route-specific and there are few, if any, arrangements to shift pilots between pilotage jurisdictions for foreign trade vessels, major shifts in shipping business between competing ports could affect the near-term availability of qualified marine pilots.

Perrow (1984) identified maritime shipping as an "error-inducing" system. He found that the economic pressures on the captain, the authoritarian social structure that belies the interdependence and complexity of operator interactions and the system itself, the structure of the marine industry and marine insurance, and the difficulties of national and international regulation all combine to make accidents highly probable and almost unavoidable.

If organizations are to prosper amid environmental uncertainty and rapid change, they need flexible and changing organizational strategies (Peters, 1987). However, the more typical response to such an environment is to retrench, adhere rigidly to outdated policies, and develop a "we/they mentality" (Janis and Mann, 1977; Meyer and Starbuck, 1993; Staw et al., 1981).

The present focus on analyzing and identifying sources of risk in the marine navigation and piloting system is hardly new. Marine safety authorities have been conscious of this need for years, although the focus has been on subsystems (see Chapter 1). With increasing sea transport of hazardous materials, this issue has assumed much more importance (Wennick, 1992). Public awareness and concern about the possible impact of accidents on the environment, in the form of pollution and personal injury, have heightened awareness of corporate responsibilities and the need to assess operational levels of risk in ports, on vessels, and for different trades and technologies (see Davidson, 1990).

Internal Organizational Processes

A dynamic organizational structure is indicated for the safe and reliable operations of technologically advanced systems (Roberts, 1992, 1993). Effective use of these systems requires that operators develop a deep intuitive knowledge of their systems and be given training to develop a sophisticated understanding of organizational processes in which these systems are applied. Also indicated is a need for flexible decision-making and the development of trust in system and operator performance. This can be developed through the training of all participants (Roberts, 1993). How well the language and culture of the marine navigation and piloting system reflect this more flexible approach affects the safety benefits that can be obtained from the use of high-technology systems and measures to improve human performance.

Shipboard Command and Control Organization

Shipboard navigation and piloting tasks are affected by interactions throughout the marine navigation and piloting system, including the operating and management practices of marine transportation companies. As discussed in earlier chapters, the ultimate authority in the operation of any ship is its master. But as the character of merchant ships and shipping have changed in the past decade, anecdotal reports suggest that the capability of the master to ensure a ship's safety is being eroded, although the degree of erosion is uncertain. Nevertheless, the traditional hierarchical structure for command, control, communications, and information (C^3I) is entrenched in the shipboard organization of most vessels. Both the language and the culture of the system and its structure assume that the captain always has the last word in decision-making and that these decisions are always correct. Yet in pilotage waters, it is the marine pilot who typically directs and controls the vessel, usually with very limited oversight by the master (see Chapters 1, 2, and 3).

The traditional command and leadership relationship has been considered necessary to maintain order and discipline, especially when faced with operating conditions that threaten the vessel, officers, and crew. But the hierarchical struc ture results in unidirectional, top-down communications. Marine language and practices that derive from this traditional structuring leave little room for the development of a culture that encourages bottom-up communication or the provision of rewards when it happens. No provision is made for bottom-up communication, a major objective of bridge team training. This may be an important deficiency in the marine navigation and piloting system (no empirical research was examined). Communication of problems detected by subordinates and solutions they may propose can be stifled by the rigidity of the traditional bridge organization and culture unless the operating company, through the master, has fostered a more receptive bridge team communications environment.

Interrelationships on the Navigation Bridge

Each member of the bridge team in confined waters has specific levels of access to information and duties to process that information with respect to C^3I. While there is some overlap, no one has complete access to all information on a traditionally configured navigation bridge. Even on high-technology ships that are ergonomically designed to support one-person operations, sharing information and support among bridge team members is still desirable in order to safely navigate the full range of hazards and conditions that affect the passage in pilotage waters. The safety of the passage depends on the ability of bridge personnel, including the marine pilot, to function as a team, the pilot's traditional role notwithstanding (see Chapter 1, 2, and 3). In almost every maritime accident involving the interactions of bridge team members, while specific errors can assigned to individual members, it is the loss of smooth functioning of the team as a whole that leads to the accident. This is a common difficulty with airline cockpit crews involved in accidents as well (Fouschee and Helmreich, 1988).

Access to information is divided among all members. The officer of the watch has most of the radio, navigation, and chart information, as well as the information from the radar or ARPA and miscellaneous instruments and instrument indicators about the bridge. The officer of the watch also keeps the logs. The master picks up bits and pieces of information of interest but is usually most informed of the visual navigation elements and the radar or ARPA information. The pilot has most of the local knowledge information about the port and, as does the master, picks up information as needed, including that derived from radio transmissions (often by using portable transceivers). Because most ships do not have a 360° unobstructed view or bridge configurations designed to support one-person operations, the master, pilot, and officer of the watch move about the bridge as necessary to perform their tasks. The helmsman has information from the instrument panel normally located above the windows on the forward bulkhead of the bridge and the steering stand about the rudder movements, ship's heading, and rate of turn. Thus, while each has access to different pieces of information, none has continuous access to all the information needed for safe passage.

Because navigation and piloting are shared tasks, communication is a key element in ensuring that each team member has all the information needed for assigned parts of the job. Beyond the sharing of information, other vital communications take place during passage. Outside communications with other ships, and with vessel traffic services (VTS) where available, are very important. These external communications are typically carried out using a VHF radio with a bridge speaker to disseminate transmissions from other vessels and shore stations. Both sides of the conversation can be heard if the other personnel on the bridge are positioned to hear the voice of the person operating the installed or portable radio and the bridge speaker. A complicating factor is that pilots often use portable transceivers to communicate with other vessels, often while the pilot is positioned on the bridge wing. Sometimes errors are made based on the assumption by bridge team members that everyone has heard the same information. Communications with the engine room are frequent and vital. The bridge team needs to know of any engine problems that might limit ability to maneuver at will. Engineers, too, need to know of any unusual anticipated maneuvers that might require adjustments to the propulsion system.

Possibly the most important communications, though, are the orders given for maneuvering the ship in pilotage waters. These are normally given by the pilot, but they are sometimes given by the master or the officer of the watch. Most of the time, the orders are relatively easy to hear on the bridge, but at times such as docking or when meeting or overtaking another vessel, the orders may come from the bridge wing. Frequently, these must be relayed by one or more persons—some of whom may not be fluent in English. All these communications can be hindered further by ship or wind noise, radio transmissions from bridge speakers, and nonessential conversations. The level of interference increases in stressful situations, when timeliness and correctness of orders are most important.

Command on the bridge is not as clear as it might seem. By law, the master is in command; however, in pilotage waters the pilot normally directs and controls the vessel's movements and gives maneuvering commands. Sometimes, the officer of the watch also gives or relays orders. Even in court decisions, navigational command-and-control, particularly as it applies to the master–pilot relationship, depends on the situation (see Chapters 2 and 3; Parks, 1982). This rather fuzzy division of authority and responsibility has contributed to some accidents (NTSB, 1988b,c, 1989a, 1993). Given the organization of the marine navigation and piloting system, the dominance of traditional bridge configurations, and legal precedents, it is likely that this peculiar relationship will continue indefinitely.

Miscues in these communications chains have also contributed to many accidents. Vessel control with respect to steering and propulsion is an example of error-prone practice. Normally, steering is accomplished by a helmsman who has no command authority. The helmsman has direct control of the ship's rudder and, thus, its course through the water. The information available to the helmsman is usually limited to that directly related to steering, including rudder angle, gyro heading, and automatic pilot setting. Steering orders are received directly from the master or pilot if they are on the bridge or by relay through the mate when conning is being conducted from the bridge wing. On ships designed with bridge control of the propulsion system, shaft revolutions and direction are usually controlled by the watch officer under orders from conning officer (normally the pilot or master). If bridge control is not available, the ship's engineer (or engineering watch officer) controls the engines based on orders relayed by engine order telegraph or voice tube from the watch officer.

Opportunities for Human Error in Traditional Practices

A typical risk analysis fault tree of the traditional mode of bridge operation discussed above would reveal an unusually large number of opportunities for human error. Most of the problems stem from reliance of the operation on accurate and timely communications; many result from the wide distribution of responsibilities for C^3I. For example, the number of possibilities for error in a simple order for a change in engine speed is alarming. First the order must be formed correctly by the pilot, then understood and relayed correctly through as many as three persons on the bridge (pilot, master, and mate). If it reaches and is understood correctly by the engineer, it must then be executed correctly. If executed properly, the throttle control, engine, gears, shaft, and propeller must operate correctly. Given that a large number of such commands may be necessary during a transit of pilotage waters, the chances for human error are multiplied substantially. This is offset to some extent by monitoring and cross-checking that has evolved as a practice of good seamanship.

APPLYING ORGANIZATIONAL SAFETY STRATEGIES TO MARINE NAVIGATION AND PILOTING

Changes in risk and economic conditions have already prompted innovation in marine navigation and piloting subsystems. This section reviews some of these ongoing developments from a humans systems perspective, including innovations in training systems. Human systems concepts for reducing risk in performing tasks are then presented. These are followed by an examination of organizational approaches for improving safety. The section closes with a summary overview of recent human systems research and development initiatives undertaken by the Coast Guard and the Maritime Administration.

Recent Innovations in Navigation and Piloting

Bridge Teams

The most widely used of the recent innovations has been the "bridge team" concept. Ideally under this concept, the master, pilot, watch officers, and the unlicensed helmsman and lookouts would be trained to operate as a team with a more cooperative structure than that found in the traditional hierarchical-bridge C^3I model. In practice, team training usually involves licensed ship's officers. Marine pilots sometimes participate in bridge team training, usually in cooperation with specific shipping companies, for example, in advance of port calls by a new class of ships. A variant is "bridge resources management" in which individuals such as pilots are instructed how to improve personal interactions in order to most effectively use the human-resources that are available on the bridge. The bridge team and bridge resources management concepts, similar to cockpit resources management in aviation, have the advantage of encouraging more open discussion and constructive questioning of orders and actions, and they might provide for better communication among all participants (Crooks and Douwsma, 1989; Douglas and Wass, 1993; Koning, 1993; Wahren, 1993). Because coordination of bridge teams does not require a substantive change in most staffing and procedural aspects of the traditional bridge model, acceptance is more likely than is acceptance of more radical change. There is some concern that excess questioning and discussion may lead to delay in carrying out required actions in emergencies. However, most advocates of the bridge team model think that this would not be a significant problem so long as training is adequate and that the benefits of the team concept outweigh the drawbacks. Pilots tend to prefer bridge resources management, because they do not consider themselves to be a member of a ship's bridge team, per se.

One-Person Bridge

The concept of a one-person bridge organization is far more radical than the bridge team. Here a single person has total control of the navigation and maneuvering of the ship at sea. However, the master and a pilot may still be required by need or regulation to be on the bridge while in pilotage waters. Several classification societies have published, or are in the process of publishing, requirements for bridge layout and equipment for this type of operation, and the International Maritime Organization (IMO) has approved testing of the concept with the approval of the flag states involved. The United States has not, to date, approved such tests in its waters.

Proponents point out that most ship accidents result from human error and, particularly, from errors in communication among members of the bridge organization. They contend that reducing the number of people involved will, given a properly designed bridge and integrated equipment, reduce the chances for error and thereby the number of accidents. They also cite the good safety record of integrated tug and barge combinations and small coastal tankers that operate in this fashion, even without the benefit of the proposed bridge design and equipment. Further, they note that because a pilot is taken in pilotage waters (for foreign trade vessels), there are at least two people on the bridge in the region of highest risk.

Opposition to the one-person bridge is focused on the additional task loading of the operator and the need for a proper lookout. Opponents contend that a single officer is not able to maintain an adequate lookout and still conduct all other duties effectively. Some concern has been voiced about the possibility of the watch becoming incapacitated or falling asleep. However, this concern might be mitigated by the availability of "dead man" alarms and other technologies that have proven effective for ensuring alertness in one-person operations ashore.

Some commercial maritime research has been conducted investigating one-person bridge concepts (Iijima et al., 1991; Kristiansen et al., 1989; Schuffel et al., 1989). In addition, the U.S. Navy has been evaluating such concepts from a defense perspective for a number of years. One published report found significantly improved track keeping and reduced stress and fatigue for one-person bridge operations as compared with traditional bridge manning and operational models (Schuffel et al., 1989).

Pilot–CoPilot Model

The pilot–copilot model is based on the arrangement used on the flight deck of commercial aircraft. To function properly, this model requires a bridge layout similar to the one-person bridge but has a two-position console. Each position is similarly configured and includes all controls and displays needed for one-person operation. Certain indicators and controls may be shared on a central console between the pilot and copilot. The consoles are located so as to allow essentially all operations to be performed while seated there.

During passage, only one watch/conning officer controls the ship at any given time. To reduce fatigue, the officers regularly alternate control, in the same manner used on airliners. When not controlling the ship, the off-duty officer assists by handling communications, scanning secondary indicators, providing lookout, keeping logs, and handling other tasks not directly involved in ship control. Most importantly, this officer acts as a supervisor, or *second pair of eyes*, observing the officer in control to help eliminate the possibility of error. In times of low risk and minimal work load, such as in open waters and good weather without traffic, the bridge may be operated by one person. Use of the latter practice must, however, consider the fact that marine accidents often occur during such favorable operating conditions.

Among the earliest proponents of this pilot–copilot operation was the

Oy Silja Line AB, which operates large, fast ferries (really passenger ships) between Sweden and Finland. The line has achieved an enviable safety record during a decade of using this model to navigate 10-hour passages at 20 knots or more, through some of the most difficult waters imaginable. Not surprisingly, the Silja Line and six other marine organizations have called on the SAS Flight Academy for assistance in developing procedures and training (Herberger et al., 1991; Koning, 1993; Wahren, 1993).

Other examples of this model may be found on hydrofoils, surface-effect craft, and other very fast vessels that simply could not tolerate the communication delays and potential for errors inherent in the traditional bridge model. In its hydrofoil development program to facilitate the transition to hands-on ship control, the U.S. Navy reportedly favored assignment of aviators to operate these vessels. The Navy has developed and uses a full-mission simulator with physical motion capabilities that are similar to visual flight simulators in order to train operators of surface-effect craft.

Proponents of the pilot–copilot model contend that it has proven in aircraft operation to be a highly reliable operation. Because there are two qualified officers available at all times in areas of high risk, advocates consider this model superior to the one-person bridge in eliminating errors, reducing fatigue, ensuring alertness, and maintaining lookout. Because actual vessel control is the responsibility of a single operator, proponents argue that the potential for communication error is all but eliminated and that decisions and action are more timely and accurate. Cooperation with the bridge team is said to be improved in that only two people are involved, and their qualifications are essentially equal.

Criticism of the model centers around training requirements and the awkward role imposed on a local pilot. Mariners are not typically trained in this type of operation, and, where it is currently in use, operators have been specially and extensively trained in the required procedures. Retraining the current pool of mariners, critics argue, would be extremely difficult and expensive. Further, the traditional role of the local pilot does not fit this model. Many pilots, particularly in the United States, are accustomed to giving rudder orders to control the ship. The pilot–copilot model is well suited, though, for track keeping with a planned route, using integrated bridge functions. In the waters where this model is most common, in Sweden and Finland, pilots have had to adapt to the operation by coming aboard with a documented passage plan.

Marine Simulation

Shiphandling simulations have been developed over the past three decades for a variety of applications, including operational training, marine casualty analysis, evaluation of vessel designs for maneuverability, evaluation of bridge equipment and aids to navigation, and assessment of particular vessels regarding suitability for a new port or transit situation. Some simulation facilities have been used for the multiple purposes of research, training, and waterway design (NRC, 1992a; Puglisi, 1987).

Computer-based and manned-model simulations are used for the training of merchant mariners. By artificially recreating real-world conditions, simulation permits individuals or bridge teams to develop or refine skills in shiphandling; bridge resources management; and in some cases, interaction with engine rooms and VTS systems. Simulation is used to aid in the training of VTS watchstanders in a few countries (not the United States), but combined development of pilot and VTS-watchstander expertise has not been attempted (Barber and Hughes, 1992; CCG, 1990, 1991a; Dijkhuizen and Regelink, 1988, 1990; Ives et al., 1992; Laroche and Côté, 1992; Routin, 1990; Transport Canada, 1989). Marine simulation is also used by some pilot organizations to refine and expand the professional expertise of marine pilots rather than to build the underlying expert skills or provide equivalent experience for pilot licensing.

Simulation training offers many benefits. The medium does not expose individuals participating to operational hazards (or, in the case of manned-models, to life- or vessel-threatening hazards). The mariner can be exposed to a wide range of operational scenarios in a substantially compressed time frame, including "worst case" scenarios that go beyond real-world safety limits. Approaches to busy harbors and channels can be simulated to prepare watch officers for approach transits, although such training is for the most part limited to undergraduates at maritime academies. Overall, the effect of simulations on behavior can be advantageous. The nature of the simulator environment—repetitive, comparative, and controlled—can help to identify individual weaknesses more rapidly than does real-world training and can mold and foster better attitudes in certain conditions toward use of proper procedures.

Impediments to the widespread use of simulators include the lack of standards for simulator design and construction, training and certification of instructors, trainee performance evaluation, cost of training, and uncertainty over the transfer of training. There are no comprehensive federal, state, local, or industrial mandates or regulations for simulation training. In addition, technical challenges must be overcome. Simulation is a highly technical art involving the integration of skills from a number of fields, including hydrodynamics, civil and marine engineering, piloting, computer science, and human engineering; in all these areas, research questions remain including

- the potential, role, and cost-effectiveness of shiphandling simulation for initial maritime education, certification, licensing, skill development, skill maintenance, indoctrination to emerging navigation and ship technologies, and determining professional competence;
- the scientific, technical, and professional bases for substituting simulation for practical experience in professional development and in the marine licensing process; and

- the requirements and capabilities for simulation validation, accreditation, fidelity, and evaluation.

To foster broader use of simulators for training, advocates could educate industry and the public regarding the benefits of simulator training, develop the various standards just described, and conduct the necessary research to fill gaps in the state of practice and to reduce simulation costs.

Reducing Risk

Command, Control, Communications, and Information

Command, control, communications, and information (C^3I) are the basic elements required for proper functioning of the bridge team. These elements must be constantly and precisely understood and coordinated if the bridge team is to perform safely and efficiently. Failures in any one of these elements, or a lack of coordination of the elements, can lead to disaster. In no other form of transportation is coordination of C^3I more challenging than on the bridge of a ship. Even in the most sophisticated operations, rarely does a single person on the bridge have complete access to all essential C^3I elements. The success of bridge operations is highly dependent on accurate and timely communications and the ability of each person involved in bridge team operations, including the pilot, to anticipate the information needs of the others.

Error Reduction

Since error rates in communication are among the highest quoted, error reduction efforts would best be directed at reducing the number of required human communications. Training might seem to be an answer. The literature, though, suggests that training may not be enough, because it provides only an order of magnitude improvement, and that improvement is only temporary unless continuous training is employed. The one-person bridge model appears to be another answer, since it does not require any communications or other human interactions for most tasks. However, because there is no active second-party supervision in this model, the single officer might commit an unacceptably high number of undetected errors of other types, at rates approaching those of communication errors. Similar errors could occur in the performance of marine pilots, who also operate with limited supervision once fully qualified. (See Chapters 2 and 3.) Nevertheless, a reduction in the number of persons involved while still maintaining an adequate level of supervision does seem to be indicated. A third approach to reducing errors lies in effective design, operations, and performance monitoring of systems (Fouschee and Helmreich, 1988; Grabowski and

Roberts, 1993; Roberts, 1993). Further, as most human error is induced, recent efforts in error reduction have focused on identifying and correcting *latent* human error in large-scale systems, in an effort to anticipate, and correct before-hand, errors and system difficulties (Reason, 1990, 1992).

Much of the manpower requirement on the traditional bridge is for the gathering and processing of data from a multitude of sources. Methods for data fusion and presentation are available to reduce the magnitude of this task. Electronic charting systems and integrated bridge consoles, for example, are designed specifically for this purpose; they can be employed to reduce the number of operators required and the dependence on person-to-person communications. On the other hand, these systems increase the task responsibilities of the remaining bridge team members and can increase task loading if not designed to accommodate the changes in the functions performed.

Another critical task that is totally dependent on communications in the traditional model is steering. As discussed earlier, the most common reasons for having a separate helmsman steer the ship are the steering systems available, the need for the officer in command of the ship to roam the bridge to acquire essential information, and the use of rudder commands for maneuvering in confined waters. An analysis of the process of giving and carrying out a steering order for a change of rudder angle to "15 left rudder" reveals a multitude of possibilities for human error. First, the conning officer must correctly determine that "left 15 degrees rudder" is the necessary change. Then, these thoughts must be verbally communicated to the helmsman using correct terminology. The helmsman then must hear and interpret the order as given and must turn the wheel the right amount in the correct direction. If, during the turn, the conning officer realizes that more or less rudder is required because of the way the ship is responding (feedback), the whole process must be repeated to effect the correction. Every step of this process is subject to human errors.

Compare this method of steering with that used in virtually every other form of transportation, wherein the person in control actually operates the control mechanism. In that method, the person thinks of the desired direction, and, through a highly reliable brain-to-motor process, moves the control the amount that experience has shown to be about right. During the turn, the controlling officer observes the behavior of the vehicle and, though another brain-to-motor process, makes corrections based on the visual feedback received. One need only imagine driving a car through a course of turns using the traditional bridge model to realize how laborious and error-prone the bridge model process is. Yet at times, even with a fully integrated bridge system, operating conditions, superstructure configurations, deck loading, difficult maneuvering scenarios, or bridge-to-bridge communications needs may necessitate that the conning officer remain unencumbered in order to maintain the "big picture."

Reaction Time

The "left 15 degrees rudder" illustration also suggests another problem inherent in the traditional bridge model: reaction time. The example includes a number of processes that take considerable time to perform. If anything is done incorrectly, significant time is required for the conning officer to recognize and confirm the error and to formulate, communicate, and carry out the corrective action. Again, this process must be compared with the near-instantaneous brain-to-motor function of the single person reacting to visual feedback.

The delays inherent in plotting position on a paper chart were discussed in Chapter 6. This process, which can only reveal the vessel's position in real-time if the vessel is not moving "over the ground," can introduce significant delays in reaction time, because plotting is not normally continuous. To detect a position error, the conning officer must either wait for the next plot to be made and then wait to receive it from the person performing the plot or estimate the vessel's position from visual or radar cues (a marine pilot is supposed to be capable of precise position estimates from such cues). If there is a discrepancy, the conning officer usually asks that the plot be confirmed, which introduces yet another delay in determining actual position (at the time lines of position were taken). Electronic charting systems, which incorporate real-time positioning information, are intended to be more accurate and timely for determining position. In addition, such systems eliminate time-consuming plotting tasks and another person-to-person communications link and source of human error.

Another impediment to quick reaction is the arrangement of the traditional bridge, which requires an officer to roam the bridge as necessary to gather and process data. This task can be time-consuming and can distract from other tasks. Roaming can delay reaction to problems, introducing the possibility of errors in interpretation of data and communication of information. Integrated bridges place all important data in view of the conning officer and often, through data fusion and automated processing, reduce the time and space needed to receive and react to information.

Automating Error-Prone Functions

Many of the routine administrative tasks performed on the traditional bridge can be automated relatively easily using available technologies. In traditional approaches to human–machine allocation decisions, tasks are assigned based on functional analyses of the capabilities of humans and machines, and of the required tasks. For instance, tasks primarily requiring motor skills are often designated for machine support, while those requiring perceptual skills are often best supported by humans, or by combinations of humans and machines.

In piloting and navigation systems, much research and development has focused on the design and evaluation of systems and decision aids which provide support for the perceptual and motor activities involved in controlling a vessel. Typically, these aids used enhanced graphics and visual representations of actual and expected ship's position, in addition to steering assistance. Such systems provide good support for the lower-level cognitive skills of piloting—trackkeeping and maneuvering—but provide little help in supporting the higher level cognitive tasks which are an important component of good piloting and navigation, specifically collision avoidance and qualitative ship management skills known collectively as the "practice of good seamanship" (Grabowski and Wallace, 1993). Support for the full range of cognitive shills—motor and perceptual—in order to anticipate and avoid errors is currently a research goal.

To the extent that machines can do a job at least as accurately and reliably as can people, technology has the potential to make bridge operation safer and more efficient, while freeing those involved in navigation and piloting to do the thinking, anticipating, and other intuitive tasks that machines currently cannot do. To the extent that technology reduces the need for interactions and communications among bridge personnel, it can reduce the probability of human error.

Microcomputers and processors already are very powerful and relatively inexpensive, and they promise to provide even more power at less cost in the near future. Software-based systems to automate appropriate bridge functions are being developed. These developments warrant a new and critical review of the traditional bridge operations model to the extent that they can provide cost-justified improvements in safety and efficiency.

Rationalization of Tasks

To derive maximum advantage from technology, a new model for bridge operations needs to be developed. The key to this effort is determination of which tasks are best done by the machines and which are more appropriately done by people. While there will not be a clear distinction in all cases, a clear vision of the desired bridge model would facilitate decision-making.

Some tasks are easily assigned to machines, simply because a machine already has proven to be significantly faster, more accurate, and more reliable than people. Such functions are primarily the simple mathematical computations required for navigation. A well-programmed computer virtually never makes an error in computing a mathematical function, while humans err frequently. Clearly, this fact suggests that the simple and repetitive calculations required to determine position, set and drift, and "course made good" can be given over to computers. With direct inputs from electronic navigation instruments and radar, such calculations can be done several times a second with very good accuracy, and they can be compared with alternative inputs and displayed in real-time on an electronic charting system. Similarly, the positions and tracks of other vessels in open water can generally be computed more accurately and faster with modern ARPA systems than they were by people; interactive positioning systems in conjunction with VTS operations has the potential to provide the same capability for pilotage waters (see Chapter 5). In cases where tasks can be accomplished with significantly greater timeliness, accuracy, and reliability through automation, continued requirements for manual performance can work against improvements in safety performance.

Some tasks will be difficult to automate but still can be automated, with thoughtful technology development. Data fusion and information display is one very important task of this type. Much work has been done in this area by the aircraft electronics industry, which has developed cockpit displays that in only a few seconds of instrument scanning convey all necessary information to the pilot. Lessons learned from these advances could be incorporated into development of integrated bridge consoles that could free the mariner from the time-consuming process of having to gather, process, and interpret all the information necessary for understanding the condition of the vessel and its environment.

Other tasks that can be performed accurately and reliably by machines are steering and track keeping. Current-generation auto pilots are more accurate and consistent in maintaining course than are the typical helmsman. The capabilities of microprocessors offer the promise of even better performance by allowing the use of more complex ship models. These new models are under development, including those with neural networks which can adapt continually to changes in the navigation situation (see Chapter 6). By combining these new autopilots with real-time information on cross-track error from electronic charting systems, a level of track keeping precision can be achieved that argues for replacing the helmsman with technology. If the helmsman position is eliminated, the trade-off is that either the master, a mate, or a qualified crewmember may have to hand steer under some operating conditions, adding to task loading.

Humans, on the other hand, do a better job of performing cognitive tasks that cannot be fully automated. Supervision of other humans and oversight of automated operations to detect malfunctions or to override systems to compensate for unplanned operating conditions are such tasks. While a person does not necessarily perform very well in recognizing his or her own mistakes, well-trained operators seem well able to spot errors committed by machines and other humans. This performance is particularly good if the supervisor is not burdened by other, nonsupervisory tasks. Assuming this is the case, the ideal bridge operations model is a fully automated vessel operating under the supervision of a full-time human supervisor, assisted by computerized expert systems, whose principal task would be to oversee the operation of the ship's systems. The operator would also need to be capable of overriding subsystems and operating them manually. Implementation of such a model is being explored by several nations—the United Kingdom, Germany, and the Netherlands (Grove, 1989; Schuffel et al., 1989). The model sets a standard that might be approached to the extent that available technology, cost considerations, and mariner professional development allow.

Organizational Approaches for Improving Safety

Safety in organizations can be improved in a number of ways. In addition to traditional human factors engineering approaches, such as attention to appropriate system and organizational design and operations, recent efforts have also focused on changes in organizational structure, decision-making, communications, and organizational culture. The following section discusses these approaches as applied to the marine industry.

Structuring

Military organizations have determined that one-way to control operations in uncertain environments is to exert tight local control. They also have learned that, as situations become increasingly fluid and dangerous, decision-making at the local level is essential. This tension between centralization and decentralization is a paradox of modern military operations.

Most theorists interested in effective organizational design sooner or later note that when organizations are tightly coupled (that is, they have well-defined, rigid decision-making processes) and consequently are fairly centralized, they become brittle and unable to respond to changing environments (see Daft and Weick, 1984; Perrow, 1984; Weick, 1976). These researchers often call for looser coupling, noting that organizations tend to experience operational or administrative problems when the coupling becomes too tight.

Perrow expands on this notion of tight coupling with specific reference to the marine industry. He notes that many systems are so complex in structure that small changes cannot make the system safe:

> The problem, it seems to me, lies in the type of system that exists. I will call it an "error inducing" system; the configuration of its many components induces errors and defeats attempts at error reduction. Discrete attempts to correct this or that will be defeated by something else; only a wholesale reconfiguration could make the parts fit together in an error-neutral or error-avoiding manner. Much of the marine system is perversely inverted. The identifiable victims are primarily low status, unorganized, or poorly organized seamen; the third party victims of pollution and toxic spills are anonymous, random, and the effects delayed … it seems to be the combination of system components that promotes error inducement, such that improving or changing any one component will either be impossible because some others will not cooperate, or inconsequential because some others will be allowed more vigorous expression. (Perrow, 1984)

Perrow's analysis focuses on the system's complexity and assumes tight coupling in potentially dangerous situations; however it does not address the loose coupling within the marine industry, much less within the marine naviga tion and piloting system. Although some tight couplings do exist, such as on the ship's bridge (this can be a detriment because of the lack of bottom-up communications, discussed earlier), the overall system is very loosely integrated.

An example of tight coupling might be an oil shipping company that, in response to the *Exxon Valdez* accident, required specific behaviors on the part of masters bringing ships into port. Such specifications, if too rigid, could constrain the use of judgment or intuition in responding to novel situations.

Thus, loosely coupled or entirely disconnected systems can cause accidents as readily as can tightly coupled systems. This point is missed in the organizational literature. The challenge to marine safety and pilotage authorities, transportation companies, industry trade associations, and researchers is to identify the degree of coupling and interdependence appropriate to the safe and effective performance of navigation and piloting tasks. No studies on large-scale organizational systems exist that could aid in determining this optimal structure.

Decision-Making

Masters, mates, and pilots navigating in confined waters are inundated with data from a variety of sources and must make crucial decisions quickly (see Chapters 5 and 6; NAS, 1981). These decisions are made in stressful environments, often after lengthy cargo watches, by an ever-smaller bridge team. Card et al. (1983) and Grabowski and Wallace (1993) offer a model of information processing and decision-making that helps explain the decision-making situation faced by mariners.

In a simple transit scenario, the pilot relies on a mental construct of the chart. In the words of the model, these data are stored in the pilot's perceptual processor and memory. Lines of position, deviations from channel centerline, and track keeping information are held in the sensory system's buffer memory while the data are coded symbolically. The cognitive system takes sensory images and knowledge from long-term memory—past experience with deviations from the present track, procedures from the nautical rules of the road, courses to steer, how to align the vessel in the waterway, and how to compensate for current set and drift. The pilot's motor system executes the results of the decisions made as commands are vocalized (Grabowski and Wallace, 1993).

Problems arise when the cognitive representation fails to map reality. For example, a serious maritime accident occurred when the captain of a large ship misinterpreted a flashing red light as a net buoy marker (Roberts et al., in press). The captain gave the wrong order, and the ship hit a rock. Problems can also occur when orders are misinterpreted or carried out incorrectly. For example, the pilot may order a rudder turned 10 degrees to the *right*, but the helmsman turns *left* 10 degrees. The resulting situation can worsen rapidly when no one is available to question the maneuver or when the organization's culture restricts any questioning.

Individual decision-making exists within the context of the system. It is apparent that such a loosely federated system creates a situation in which decision-making also is uncoupled (that is, the affected parties do not communicate). Since the days of Henry VIII, maritime nations have recognized the need for some kind of connection between the port authority and the ship to transfer local navigation knowledge. This need led to establishment of the piloting industry, which has changed little over time. Viewing the ship and pilot as a system unit, the notion of a pilot as a navigation aid introduces the opportunity for checks and balances.

The social-psychological research on decision-making focuses primarily on how individuals make decisions in response to group characteristics (Scott, 1992; Simon, 1956). Some attention has been devoted to distributed decision-making, which in many ways is characteristic of the marine industry. However, this concept makes an assumption—that decisions are tied together across a system—that does not hold true for the marine system. For the most part, in any port, individual decisions made aboard yachts, tugs, ferries, and other vessels are totally independent of one another.

> *Distributed decision-making* is a neologism that has been deliberately chosen to capture the cumulative change in the nature of multi-person decision-making that has been wrought through advances in technology. Those advances have increased the distance over which individuals can maintain contact, the speed with which information and instructions can be shared, the amount of information being created and the accompanying information load, the opportunities for monitoring operators' behavior, and the possibilities for automating instructions (for example, through expert systems, computerized pattern recognition).
> (NRC, 1990b)

To the extent that truly distributed decision-making exists in the marine industry, existing research could be integrated to illuminate inherent characteristics of that decision-making. If a feature of distributed decision-making is the interdependence of the parts of the system, then it would be useful to have an understanding of the cognitive maps held by the various operators. Cognitive maps vary depending on knowledge of the system, status within it, and so on.

An important characteristic of individuals in the marine system is trust—trust in the expertise of other operators, trust in the behavior of each vessel, and trust in the system itself. While trust has long been a major issue in the organizational literature, there is no systematic research on its place in the marine industry. Clearly, if a ship's master cannot trust the knowledge, skills, and intuition of a local pilot, the master is handicapped severely in operating the ship in unfamiliar waters.

No research exists on decision-making involving multiple individuals in the marine environment. Only one study is related even tangentially. Roberts et al.

(in press) studied decision-making aboard two nuclear-powered aircraft carriers. (No attempt was made to tie the carriers to shore installations or to navigation aids such as a VTS or the GPS.) These authors found that the decision locus migrated within the organizations. Important decisions could be made by a number of individuals, even at the lowest organizational level. Factors such as accountability, responsibility, uniqueness of the problem, and characteristics of the external and internal environment affected decision dynamics. A model was developed to account for movements of the decision locus in these organizations.

Many other important issues concerning multi-individual decision-making require research. System designers and users need to know how shared knowledge develops, what knowledge requires sharing, and the nature of barriers to sharing knowledge (Bowers et al., 1991). The distribution of responsibility and accountability also could be examined, particularly with regard to pilots and other navigation aid services. Research designs could be adapted from those used in aircraft cockpit team research (for example, by the National Aeronautics and Space Administration) and from research conducted by the U.S. Navy on team decision-making (Driskell and Salas, 1991).

At the organizational level, a number of other issues warrant attention. An organizational analysis may focus either on one organization (such as a shipping company) or on the network of organizations constituting the marine system (such as tugboat companies, passenger ferry companies, shipping companies, and recreational users). Because no investigations of larger systems have been conducted to guide everyday operations, it can only be assumed that at least some factors thought to be important in organizational behavior also are important at the larger system level. Myriad issues could be the focus of study. Recently, some research has been devoted to understanding how organizations learn (Attwell, 1992; Huber, 1991; March et al., 1991). How they learn certainly influences how they approach multiparticipant decision-making tasks.

Communication

In his analysis of the Tenerife air disaster, in which 583 people on a Pan American 747 and a KLM 747 were killed, Weick (1993) makes the following points:

> First, part of any job requirement must be the necessity for talk. Strong, silent types housed in systems with norms favoring taciturnity can stimulate unreliable performance because misunderstandings are not detected. Of the four implications for managerial practice derived by Sutton and Kahn (1987) in their influential stress review, three concern talk: be generous with information, acknowledge the information functions of the informal organization, do not hold back bad news too long. Rochlin, LaPorte, and Roberts (1987) find that reliable performance and amount of talk exchanged co-vary.

> What our analysis of Tenerife has uncovered is the possibility that with communication a complex system becomes more understandable (you learn some missing pieces that make sense of your experience) and more linear, predictable, and controllable.
>
> The recommendation that people should talk is not as simple as it appears, because one of the problems at Three Mile Island was too many people in the control room talking at one time with different hunches as to what was going on. The din created by tense voices plus multiple alarms, however, would make it all but impossible to single out talk as uniquely responsible for confusion, mis-diagnosis, and delayed responding. The crucial talk at Three Mile Island should have occurred in the hours before the control room got cluttered, not after.
>
> If things do not make sense, speak up. This is the norm that needs to be created.

Multiple distributed decision-making is impossible without communication, and communication is the vehicle through which the culture of an organization is conveyed. It has long been known that in situations where there is a lack of trust, communication is distorted (Gibb, 1961; Mellinger, 1956; O'Reilly and Roberts, 1974, 1976). Maintenance of trust in organizations is an ongoing process (Schulman, 1993), and mechanisms need to be in place to ensure that this process is sustained.

Other variables are also important in the communication process. For example, the nature of desirable feedback, and how to make best use of it, is not defined clearly within the marine industry. At the organizational level, to the extent that distributed decision-making is desirable, it is important to understand existing communication networks in ports and along waterways. The various roles individuals play in networks determine what they say and the response they receive (Monge and Eisenberg, 1987; Tichy and Frombrun, 1979).

As discussed in Chapter 5, marine traffic regulation, particularly with regard to VTS systems, is voice communication intensive. Because of reliance on voice radio for virtually all information, from routine through emergency situations, VTS operations can compound communications problems. Information saturation can compromise rather than increase safety. So too can selective screening of information, transmission of important information at inopportune times (such as when two vessels are engaged in bridge-to-bridge communications to avoid or alleviate "in extremis" situations), and reliance on the inefficient means of radio monitoring to provide a complete traffic picture to each vessel's pilot. Electronic data links, already available in the military and beginning to make a debut in commercial marine operations, provide a technological capability that could be used to give more complete information to a vessel for onboard interpretation and use (see Chapters 5 and 6).

The airline industry and its regulator, the Federal Aviation Administration, have developed a communication system employing a highly stylized vocabu lary that is understood clearly. (As discussed in Chapter 1, a similar vocabulary is available for marine operations but is not widely used.) Even private users must conform to certain standards. The network is fairly well integrated, linking more organizations across a larger geographical area (the entire United States and Pacific Ocean region, for example) than is evident in the marine industry. Some of the aviation industry's characteristics may be appropriate for the marine industry, as discussed in Chapter 5.

Culture

Ideologies and values (that is, culture) determine behavior (Beyer, 1981). The development of a culture of safety and reliability along the waterways has become increasingly important to the public. The various cultures of the various segments of the marine industry are the glue binding these segments together (J. Martin, 1992; Ott, 1989; Smirchich, 1983). Public outcry and legislation, such as the Oil Pollution Act of 1990, place external pressure on the various segments to develop cultures in which safety is a priority. Furthermore, when pilots find themselves potentially liable for large sums of money, their behavior may be different—and perhaps too rigid to be safe—than it would be under more realistic liability conditions. The United States no longer can afford a marine industry in which participants see themselves as "iron men in wooden ships." The growing interdependence of participants, the pace of technological development, and the sheer size of some vessels (particularly those carrying toxic chemicals and petroleum products) combine to demand a culture of reliability, because the skills and knowledge of teams rather than individuals increasingly are required.

In the research literature on safety and culture, very few studies focus on the safety aspects of culture (Koch, 1993). These aspects are poorly understood in organizations generally and not at all understood in the marine industry. However, because of the growing interdependence of individuals in this industry, it is clear that authoritative attitudes cannot be tolerated. It is also clear that when large shipping companies downgrade shipboard jobs and pay little attention to crew skill or quality of life, a negative message about the importance of shipboard jobs is sent to crews.

The various cultures in the marine industry may vary too widely in nature and be insufficiently understood to ensure the safety of the system. A challenge to the industry is to decide how best to develop reliable and safe organizational cultures.

Recent Human Factors Research and Development

The Coast Guard, responding to recommendations to improve its capabilities to address human performance in marine safety and the *Exxon Valdez* accident, initiated a human factors program. The agency developed a comprehensive taxonomy to guide data collection (Dynamics Research Corporation, 1989) and then upgraded its marine casualty data collection program to better collect human systems information. This effort includes the training of field personnel to achieve this objective. Data collection under this revised program has only recently begun, so the availability of improved human systems data pertaining to marine casualties is several years away, depending upon program success. The agency has also developed an integrated plan for human factors research and development. Research protocols have been identified in the areas of: (1) manning, qualifications, and licensing; (2) automation design; (3) safety procedures and data; (4) communications; and (5) organizational practices. The objective of the program is to establish an empirical human factors technical basis for developing technologies and regulations (Sanquist et al., 1993). The agency is also sponsoring an ongoing assessment of ship bridge simulation training.

Although the research and development budgets of the Maritime Administration have been severely reduced over the past decade, the agency has continued to sponsor research in advanced navigation technology relevant to human performance. The administration's most significant recent research was development of the Shipboard Piloting Expert System, which drew heavily on technological developments in the aerospace and defense sectors. The agency also initiated efforts to establish an interagency cooperative research program to advance national capabilities in marine simulation. Maritime Administration-sponsored research and development during the past five years includes: (1) development of a shipboard piloting expert system, (2) investigation of the feasibility and applicability of fitness-for-duty monitors to determine readiness to stand watch, (3) development of a computer-based shipboard system to optimize vessel passage planning to avoid heavy weather, (4) development of an onboard ship maneuvering simulator, and (5) co-sponsorship of an ongoing examination of ship bridge simulation training.

8

Research Needs

SUMMARY

Marine transportation research is largely focused on development of high-technology systems. Research literature on the marine navigation and piloting system, and on human and organizational systems in marine transportation, is virtually nonexistent; the information that is available is very limited and dated. There is no systemic or cohesive approach to research and development for navigation and piloting technology, aside from the Coast Guard's longstanding efforts to continually update and improve short-range aids to navigation. No research program concentrates on human systems or navigation and piloting safety.

Specific research is needed on marine safety systems, waterways management, navigation and piloting technology, port-state versus flag-state policy, navigation and piloting practices, and human systems. Although research needs cross missions of various agencies, the Department of Transportation has the capability to coordinate a cooperative research program for marine transportation. The Department of Transportation has the requisite agency missions, research capabilities, and ongoing navigation-technology research sponsored by the U.S. Coast Guard and Maritime Administration.

INTRODUCTION

This chapter builds on the analysis of the marine navigation and piloting system and gaps in the state of practice presented in the preceding chapters. It is a compendium of research implications from the earlier chapters.

THE MARINE TRANSPORTATION RESEARCH ENVIRONMENT

While considerable research and development is in progress on advanced ship, navigation, and vessel traffic service (VTS) systems, the focus is principally on developing the technology rather than its application and human systems implications. Historically, most marine navigation and piloting research can be characterized as

- primarily directed at the development and acquisition of hardware (and more recently, software);
- lacking a systems perspective to guide funding, acquisition, or evaluation of research programs;
- reliant on inadequate or inappropriate data, notably Coast Guard marine casualty data, for underlying empirical support (these data are incomplete; often inappropriate to the issues being investigated, and in some cases, misleading); and
- exhibiting little intra- or interagency coordination and seldom leveraging related aerospace and defense research and development (Grey and Krop, 1979).

The marine industry is almost bereft of a research literature that address the systems impacts of organizational processes, safety (in a quantitative or qualitative fashion), risk, and human systems. This is a major gap that severely constrains and complicates analysis and determination of methods for improving navigation and piloting. In addition to these historical factors, there are two major difficulties with any plan to develop a research program that addresses navigation and piloting safety:

1. the lack of a cohesive research program within the Coast Guard (GAO, 1993a), particularly with respect to research on navigational and piloting safety and human systems; and
2. the lack of any research program, aside from that of the Coast Guard, that is focused on navigational and piloting safety.

The first difficulty results in a lack of consistent, concentrated attention on safety and human factors issues in navigation and piloting except when external events brings public scrutiny on them. The second difficulty results in an over-extended agency (the Coast Guard) with limited resources to devote to navigation and piloting safety matters. Meanwhile, other entities, principally the Maritime Administration (MARAD), the National Oceanic and Atmospheric Administration (NOAA), and the National Transportation Safety Board (NTSB) do not effectively participate in needed maritime navigation and safety research. This is primarily due to lack of resources and, in the case of the NTSB, the absence of a research and development mission. The U.S. Army Corps of Engineers conducts considerable applied research related to navigation, principally with respect to channel design and maintenance, but it does not address piloting practices, except to the extent that these practices relate to initial project design-dimensions. Research is not performed into actual piloting practices once a federal navigation project has been constructed (NRC, 1992a).

While pioneering research in human systems was undertaken by MARAD from the mid-1970s through the mid-1980s, this effort has been virtually eliminated over the last 10 years. This change coincided with privatization of operations at the MARAD-owned Computer Aided Operations Research Facility and a change in focus by the private operator from fundamental research to applied research and training (NRC, 1992a). Also concomitant were severe reductions in MARAD's research and development program, from over $25 million in 1975 to about $1 million in 1993, and the equally dramatic reduction in the size of the U.S. merchant fleet (Marine Board, 1991; Phillips and Weintraub, 1993).

Thus, there are research needs at the systems level in marine navigation and piloting as well as in the various subsystems (see Chapters 1 and 2). Research is especially needed in

- marine-systems safety, including risk and safety performance in piloting waters;
- waterways management, including marine traffic regulation, and VTS and waterways management systems;
- navigation and piloting technology (including aids to navigation);
- port-state versus flag-state policy;
- navigation and piloting practices; and
- human systems.

ELEMENTS OF AN HOLISTIC RESEARCH PROGRAM

Marine-Systems Safety

Marine safety, risk, and exposure vary widely, even within the same port and waterways complex (see Chapter 4). Therefore, careful assessment of safety performance, including the identification and assessment of underlying causal factors in marine accidents and preventative measures that might be applied, would result in a more informed basis for problem solving. Alternative approaches to assessing risk and determining where improvements can be made clearly are required. Research is needed for

- an interdisciplinary exploration of the relationship between appropriate cultural components of a highly reliable, safe marine system;
- development of a standard methodology for assessing risk and safety performance in marine transportation, including methods for data normalization across port, waterway, and river systems;
- development of a systematic vessel, company, and flag-state performance-monitoring program to aid in a holistic examination of (1) waterways

safety; (2) the impact on safety of reductions in shipboard personnel, use of less experienced officers and crew, and inadequate maintenance; and (3) the risk variables that affect development and implementation of safety improvement measures;

- development of automated safety-information systems, including real-time and intelligent data sources, integrated shipboard–VTS data bases, and marine casualty and incident data;
- *careful* development of accident/incident reporting forms, utilizing a detailed study of the nature and granularity of the data required for both quantitative and qualitative accident/incident assessments and analysis;
- development of a training and education regimen for Coast Guard and other marine accident investigators, so as to ensure adequate assessment and knowledge of the impact of human factors in marine accidents and incidents;
- evaluation of the utility of various safety and performance measures, including those assessing performance, reliability, and safety; and
- statistically valid assessments comparing the performance of marine pilots performing docking services with that of docking masters in the same port, as well as a non-advocacy assessment addressing the safety of tug and barge operations relative to oceangoing ship operations in navigable waters of the United States.

Waterways Management

It is difficult to determine whether systemwide waterways management problems exist, primarily because there is no standardized method of normalization and ranking for casualty data. In addition, the existing casualty data are not a complete reflection of the overall nature of safety problems in any one port area (Maio et al., 1991; Young, 1992). Waterways management research is needed for

- development of complete safety data and systematic performance assessments of the marine traffic safety system, as has been identified in previous National Research Council reports (NRC, 1990a, 1991a);
- development of reliable data on the range of risk factors identified in order to support complete risk assessments, which includes development of a near-miss reporting system, an exposure data base, and a comprehensive risk assessment program;
- development and evaluation of alternative marine traffic regulation models including (1) direction of vessel maneuvering by shore-based pilots in consultation with colleagues aboard vessels; (2) expansion of current VTS systems into marine traffic regulation networks, with pilots remaining aboard ships; and (3) expansion of current VTS systems into additional ports for navigation information purposes only;

- development and evaluation of a prototype marine traffic regulation system modeled on current aviation practice; evaluation of the operational prototype would include assessments of (1) factors determining system success, (2) factors particular to the maritime environment, and (3) capabilities required to successfully operate such a marine traffic regulation system; and
- development of a standardized analytical method for assessing VTS effectiveness with respect to port, waterway, and regional data.

Navigation and Piloting Technology

Just as an understanding of risk in local operating environments is important for the pilot, it is also important in determining opportunities for universal and system-specific improvements in safety and economic efficiency. The following research is needed:

- assessment of alternative means of communications, including electronic data transfer and interactive transmission of traffic and position information, to sustain and perhaps improve the safety benefits achieved through vessel-to-vessel-to-VTS communications;
- shipboard and empirical assessments of the performance and usefulness of adaptive steering systems, including those employing fuzzy logic, neural networks, and learning technology;
- empirical and shipboard evaluations of the role and contribution of electronic chart display and information systems (ECDIS), in at least three configurations: stand-alone mode, embedded within an integrated bridge system (IBS), and coupled to an intelligent integrated bridge or piloting system configuration;
- a comprehensive assessment of the *different levels* of ECDIS display including evaluations of the contribution and usefulness of simple, microprocessor-based displays of electronic charts with limited voyage planning capabilities through sophisticated engineering workstation-based systems with a variety of features (such as radar overlays/underlays, electronic charts, warnings and alarms, and voyage planning capabilities);
- development of standard user interfaces, displays, communications modes, and training procedures for shipboard navigation and piloting technology; this work would include standardization and retrofitting of existing equipment, as well as implement new technology (such as Global Positioning System (GPS), ECDIS, Automatic Radar Plotting Aid (ARPA), IBS, and expert and decision support systems);
- assessments of integrated real-time positioning systems, environmental information, automated decision aids, and shore-based navigational support services in order to reduce the potential for human error; assessments need to cover "technology-assisted" and "VTS-assisted" accidents;

- empirical and shipboard evaluations of the contribution and value of various forms of simulation and virtual reality to ship- and shore-based training; and
- improvements in traditional aids to navigation to improve visual and electronic acquisition under all operating conditions.

Port-State Versus Flag-State Policy

In view of the increasing importance of the United States as a port-state, the following research is needed

- assessment of the impact of environmental constraints on shipping companies and ship operations;
- assessment of policies for ports and waterways in which the range and variation in technologies and nautical knowledge are increasing;
- development of flexible organizational strategies and structures to respond to growing environmental uncertainty; and
- development of standardized measures, and information and decision support systems, for identifying, tracking, and managing substandard ships in U.S. coastal waters.

Navigation and Piloting Practice

The efficacy of certain licensing and operational practices cannot be fully resolved by analysis of existing data and safety studies. Research needed to provide a more complete basis to guide improvements in the marine navigation and piloting system includes:

- empirical assessments of the performance of professional-development processes for federal pilots, involving the establishment of benchmarks for comparative safety analysis;
- assessments of projected shortages of qualified deck officers by the next decade, the impact of drawing on nonmaritime labor pools to reduce labor costs, and reported declines in the overall professional qualifications of deck officers;
- development and outcome assessments of standardized professional development, recertification, and continuing professional development programs for marine pilots;
- non-advocacy (that is, objective) assessments of the safety and effectiveness of pilotage in the shipping and coastal towing industries; and
- development of a prototype (industry or Coast Guard) accredited training program for shipping and tug and barge masters, operators, and mates.

Human Systems

In the maritime world, human systems concerns are all but ignored in decision-making processes, technology development and use, and systems interfaces. Improved ways to develop and assess professional qualifications are needed. To address the lack of human systems input to navigation and piloting systems, research is needed in the following areas:

- assessment of a variety of factors that affect safe and reliable marine operations, including: (1) tradeoffs between bridge team skill mixes and crew size; (2) checks and balances in marine decision-making processes; (3) the possibility, appropriateness, and need for truly interconnected distributed decision-making within and across marine systems; (4) analysis mechanisms for improving trust within and across various segments of the marine system; (5) "shared knowledge" within bridge teams and among bridge teams, VTS, and pilots, as a foundation for empirical assessments of decision-making processes on ship's bridges and the links among these processes and their external environments (such as VTS, shipping companies); and (6) crew requirements in work environments with increasingly sophisticated technology;
- reviews of available or near term fitness for duty human performance testing methods, and development of acceptable means for assessing fitness for duty of crewmembers performing critical navigation and piloting tasks;
- assessment of the impact of manual and electronic charting practices (that is, plotting, display of icons, use of color, and so forth) on human performance;
- assessment of the impacts of electronic piloting decision aids on ship's officers and pilots, particularly the user's ability to separate from the decision aid in sufficient time to avoid collisions or groundings when it is providing erroneous advice;
- assessment of the various uses of marine simulation, including (1) its use in entry-level and proficiency training for marine pilots relative to traditional apprenticeship methods; (2) use of interactive simulator training and testing courseware and devices, including the potential application of these devices in marine licensing processes; and (3) development of marine simulation as a valid tool for establishing maximum work hours for watchstanding; and
- development of models and procedural task lists for critical watchstanding functions, and assessment of means for preventing human error in performing these tasks.

ESTABLISHING A RESEARCH PROGRAM

There is a long history of federal involvement in the development of civilian technology. This includes such technologies such as radar, a military technology that has been commercialized (NRC, 1992b). Research that would advance navigation and piloting practices and technology crosses the missions of the Coast Guard, MARAD, NOAA, and Army Corps of Engineers. Such research is also of interest to the NTSB (which periodically undertakes research related to specific marine accidents the board is investigating) and the U.S. Navy.

Because research and development budgets for marine navigation and piloting are small relative to the involved agencies' research and development budgets in other areas, every effort must be made to maximize the value of resources that are available for fundamental marine navigation and piloting research. In this regard, a cooperative research program is an attractive concept because of existing mission responsibilities related to navigation and piloting. Further, the Coast Guard, MARAD, NOAA, Army Corps of Engineers, Navy, and the marine industry already participate to some extent in cooperative research. One such example is the ECDIS testbed project (see Chapter 6) involving, among others, the Coast Guard, MARAD, NOAA, and several marine transportation companies.

The Department of Transportation (DOT) is principally responsible for safety of the marine navigation and piloting system. The department maintains research and development capabilities for transportation including the Volpe National Transportation Research Center; the Coast Guard (part of DOT) maintains a 120-person Research and Development Center. In view of the department's transportation safety mission and the ongoing navigation research and development programs of its maritime agencies, the Department of Transportation appears to have the infrastructure and mission responsibility that would be necessary to coordinate a cooperative marine navigation and piloting research program.

9

A Vision of the Future

This chapter represents the committee's perspective on the major changes that are in progress and that are likely to drive the marine navigation and piloting system over the next decade. The vision also includes high-level findings by the committee, supported by evidence and analysis in the report, in areas where action is needed to derive the greatest benefit from these trends while avoiding potential pitfalls. These findings form the foundation for the specific conclusions and recommendations in Chapter 10.

IMPROVING SAFETY PERFORMANCE

Success in reducing operational risk in shipping will depend heavily and directly on measures to improve human performance. Human causes are major contributing factors in most marine accidents. The research literature needed to support improvements in the marine navigation and piloting system, especially research related to human systems and organizational processes, is limited; this research base needs to be developed as a foundation for providing clear and specific prescriptions for improvement. Nevertheless, analysis of available facts and anecdotal information provides a sufficient basis to guide a range of near- and long-term improvements in human performance, organizational structure and processes, and the application of technology to reduce operational risk and improve navigation safety.

Scope of Needed Improvements

Improvements are needed throughout the entire marine navigation and pilot ing system, nationally and internationally, in human systems, organizational structures and processes for interdependent decision-making and official oversight, and navigation technologies. Action by the United States, other nations, and international bodies will be essential in addressing the full range of operational and environmental risks related to construction, maintenance, outfitting, qualifying officers and crews, manning, and operation of U.S.-flag vessels and the many foreign–flag vessels in U.S. trade.

SPECIFIC AREAS FOR IMPROVEMENT

Enforcement of Marine Safety Laws and Regulations

Port-state control actions by the United States to motivate improvements in the operating practices of foreign-flag ships will become increasingly important, as small size and economic competitiveness of the U.S. merchant fleet provide limited leverage for negotiating improvements in international marine safety measures. The imposition of unilateral measures by the United States to force improvements to reduce operational and environmental risk will depend on the adequacy of international marine safety guidelines, the degree to which flag states adhere to them, and the effectiveness of port-state control in enforcing flag state international treaty obligations.

Marine Pilots

The role and importance of U.S. marine pilots in ensuring the safe operation of foreign-flag ships in U.S. waters will grow, regardless of technological advances; a marine pilot is the first, and often the only, representative of national interests routinely aboard foreign-flag ships transiting pilotage waters. Requirements for pilotage of U.S.-flag vessels in coastwise and foreign trade will continue to be important in ensuring the expert local knowledge needed for safe navigation in U.S. ports, waterways, and their immediate approaches. The present U.S. structure for pilotage will need to be improved to adequately support pilots in these functions and to ensure the sufficiency of their professional development.

Marine Traffic Regulation

The regulation of marine traffic, primarily through vessel traffic service (VTS) operations, will grow in importance as a method for improving organizational structure and for directly influencing safe vessel operations, including vessel approaches to coastal waters. Development of installed and portable interactive navigation systems will provide a capability for electronic data transmission between vessels and shore stations. In ports where traffic management is not needed, VTS operations no longer will involve human-intensive shore-based processing and interpretation of encounter-specific and area-wide navigation information but rather electronic transmission of this data for onboard interpretation by masters, mates, and marine pilots. In these cases, the shore-based VTS could function as an information system, perhaps with safety oversight responsibilities. In such instances, safety oversight will provide an additional defense against human causes of marine accidents, such as misinterpretation of maneuvering situations. Coast Guard consultation and coordination with marine pilots, mariners in the shipping and towing industries, and other members of the maritime community will become more important as a principal means for obtaining the expertise and advice necessary to guide effective marine traffic regulation.

Surveys of channel conditions for determining the need for maintenance dredging and dissemination of related hydrographic information, especially to marine pilots, will become more important as channel improvements continue to lag behind modern ship hull forms and maneuvering performance. Port calls by ships that exceed channel design criteria will increase in number. Marine traffic regulation and marine pilotage authorities will require technical support in assessing the adequacy of channel design to support these operations.

Navigation and Piloting Technology

Advanced navigation technologies offer great potential to provide instantaneous and highly accurate positioning support under all operating conditions and to permit adherence to more-precise paths than are now possible. Once the Differential Global Positioning System is fully operational and a suitable electronic chart suite is available, electronic charting systems will become standard operating equipment. Electronic charting systems that consist of at least an electronic chart and real-time position data, and which meet legal requirements for navigation, could achieve universal commercial use following the examples of radar and very high frequency radio, although international action may be required for this to occur. The adopting of Electronic Chart Display and Information Systems (which by international and national definition be considered equivalent to paper charts for use in navigation), if it occurs as expected, will necessitate a radical change from print publications to electronic media as the method of disseminating updates in hydrographic information. Installation of fully integrated ship bridges will be limited, with the primary application on new ships and some retrofitting of older ships, such as those carrying petroleum cargoes.

Significant institutional obstacles and unresolved liability issues concerning the reliability and use of electronic charts will constrain full use of these systems over the next 5 to 10 years. Also constraining their use will be the imperfect hydrographic data available for navigation. These data are far less accurate and complete than are the emerging electronic navigation positioning and display capabilities that could use them. New and more comprehensive data need to be collected. Meanwhile, a proliferation of equipment types, capabilities, and configurations will emerge in the rush to market advanced positioning equipment. Comprehensive technical and operational standards, some of which are under development, are urgently needed to guide these developments. The new technologies will change and expand professional development requirements for ships' officers and marine pilots. Professional regulation and training programs and capabilities will need to be responsive to these changes in order to ensure proficiency in the use of high-technology navigation systems and maximum benefits from their application in reducing operational risk.

Traditional Aids to Navigation

Traditional aids to navigation will continue to be useful into the foreseeable future, particularly for marine pilots. Although reliance on aids will continue to vary by operating environment, pilots will find them essential as a point of comparison for assessing the capabilities of advanced navigation systems in piloting waters. Visual and lighted ranges will continue to be particularly important for navigation in restricted waters because of the reference they provide for channel alignment and drift. Enhancements to improve the visibility of ranges are needed; the development of electronic ranges that can be used during periods of reduced visibility would be particularly useful.

Technology and Crew Size

Economic interests will continue to motivate efforts to replace rather than supplement operating personnel with advanced technology systems. Some operators of foreign-flag ships on regular routes may seek to reduce operating costs by attempting to substitute advanced navigation technologies for local marine pilots. Replacement of vessel personnel with automated systems could increase the functional responsibilities of the remaining personnel while also leaving vessels with minimum crews during operations in pilot waters where hazards abound, or during emergencies aboard ship or in the waterways. Such operating conditions and contingencies may necessitate requirements for additional navigation and deck support for transits of pilot waters and for docking and undocking evolutions.

FEDERAL AGENCY ROLES

To improve the marine navigation and piloting system, cooperative efforts will be required among the federal agencies with maritime responsibilities. Federal leadership with a broad, multi-agency perspective will be needed to set a well-charted course that maximizes the resources that can be applied to operations and to maritime research and development. Organizational relationships and processes will need to be redefined and improved to achieve these objectives. Federal support of marine education and training in the shipping and towing sectors will need to be expanded, particularly as a means for improving human performance and reducing operational risk. Continued federal sponsorship of marine research and development for advanced ship and navigation systems will be essential in facilitating introduction and use of these technologies by U.S.-flag vessels.

National measures to ensure the safety of all shipping in federal waters will remain a U.S. Coast Guard responsibility, although that agency's resource constraints across its multimission responsibilities are likely to continue. Apart from marine pilotage and special environmental safety requirements, such as for tug escorts, exercise of marine safety measures by U.S. coastal states will be limited to those areas where the federal government has not acted or where parallel jurisdiction exists.

10

Conclusions and Recommendations

Maneuvering ships safely through narrow, shallow, and often congested channels is a challenging task for even the most skillful shiphandler. The marine operating environment is a complex, highly interdependent system. It encompasses waterways, vessels, human operators, navigational aids, and a supporting infrastructure for pilotage, vessel and port management, policy and regulation, and professional development. When the system performs well, the regional and national economies, the vessels and their crews, populations near ports and waterways, and the natural environment all benefit. But over the past decade, the safety, effectiveness, and efficiency of navigation and piloting have become major concerns. Although by many measures safety has improved over the past several decades, in the eyes of the public, major shipping disasters resulting in extensive pollution have brought into question the merchant mariners' professional capabilities to operate safely.

Clearly, major marine accidents deserve attention, particularly in terms of prevention or mitigation measures. Public attention has opened a window for reasonable and positive changes in the marine navigation and piloting system. System improvements need to be carefully crafted and implemented to avoid unintended side effects. A steady hand at the helm is needed to steer implementation through the changes projected in Chapter 9. The following recommendations are intended to help chart a well-informed, prudent course.

The Committee on Advances in Navigation and Piloting accepts and endorses the traditional concept that pilots are local experts in whom special trust and confidence are placed for the safe navigation of the vessels they serve. Those whom society officially recognizes as pilots have a long history of dedicated and expert service to uphold. By longstanding maritime tradition, they are held to high standards of professional competence and official accountability. This tradition should continue. The conclusions and recommendations expand on this fundamental view by prescribing a strategy for reducing operational and environmental risk and for improving safety performance, thereby enhancing public confidence in the marine navigation and piloting system and its pilotage component. Whether or not pilotage as practiced in the United States satisfies this fundamental view of the pilot is a central focus of this chapter. Recommendations are numbered for convenience of reference; no priority order is implied.

System organization, operation, and overall performance could be substantially improved to reduce operational risk by a more systematic accounting of interactions among system components. The marine navigation and piloting system is characterized by large disparities in its administration and standards of performance and by limitations in safety data that constrain informed oversight. The system is also characterized by considerable polarization over safety, economic, and jurisdictional issues that have prevented resolution of conflicts over marine pilotage and inhibited system-wide regulation of vessel traffic. Specific improvements can be made in system organization and integration, human systems, marine pilotage, waterways management, navigation and piloting technology, and marine research and development, as described in following sections.

MARINE NAVIGATION AND PILOTING: INTEGRATING THE SYSTEM

The organizational structures within the marine navigation and piloting system range from a well-established hierarchy for decision-making on a traditional ship's bridge to the more common, informal structure that prevails for system-wide decision-making, including the organizational structure used for vessel traffic management. The loose nature of organizational structures contributes to lapses in human performance. These varying organizational structures, and the decision-making that results from them, are proximate or contributing causes in many marine accidents.

Little attention has been paid to marine navigation and piloting as a system; instead, previous assessments and investigations have focused principally on performance of specific vessels in specific circumstances. The systemic elements—navigation and piloting tasks, technology, human systems, governance, and the organizational environment in which they operate—have been assessed in varying degrees, but their interactions and relative importance in reducing operational and environmental risk are not well understood. Little organizational research has been conducted by the federal government and the marine industry that would improve the marine community's understanding of the system, its elements, and their interactions. This lack of understanding, together with the informal integration of the marine navigation and piloting system, inhibits re duction in risk with respect to modern expectations for safety and environmental protection.

Understanding Risk in the Marine Navigation and Piloting System

Because of the interdependent nature of maritime navigation and piloting operations, these operations must be understood as a system. The understanding of risk in navigation and piloting can be improved by assessing system elements, their interactions, and their interactions with the environment in which they operate. Planning, management, administration, research activities, and recommendations for improvement must recognize the interdependence of system elements and take their interactions into account.

RECOMMENDATION 1: The Department of Transportation, in consultation with the Department of Commerce and the Department of the Army, should sponsor a cooperative program of continuing risk assessment involving the U.S. Coast Guard, Maritime Administration, National Oceanic and Atmospheric Administration, and U.S. Army Corps of Engineers. The program should include development of a standard methodology for assessing risk and safety performance (at the vessel, individual mariner, fleet, port, and regional levels) in order to improve understanding of risk in navigation and piloting. This methodology should include standard methods for data collection and normalization of data across port, waterway, and river systems. (See also recommendation 37.)

RECOMMENDATION 2: The Department of Transportation, in consultation with the Department of Commerce and Department of the Army, should undertake a cooperative, multidisciplinary research program involving the U.S. Coast Guard, Maritime Administration, National Oceanic and Atmospheric Administration, and the U.S. Army Corps of Engineers, in order to better understand risk relationships. The research program should investigate the interaction of the essential elements of a highly reliable, complete, and safe marine navigation and piloting system. This research should involve subject matter experts from the marine community. (See also recommendation 37.)

Casualty Reports and Safety Records

Although marine accident investigations by the National Transportation Safety Board, the Coast Guard, and state boards and commissions often provide valuable information about particular accidents, available safety data are inadequate for valid statistical evaluation and comparisons of pilotage systems, even those covering the same routes. This is a longstanding problem in marine-safety analysis and should be corrected. An accepted methodology needs to be developed for comparing safety records across pilot routes and piloting functions.

RECOMMENDATION 3: The U.S. Coast Guard should review and improve its existing programs and capabilities for collecting and analyzing marine accident, incident, and near miss data; investigating groundings, collisions, and other marine accidents and incidents; and reporting these investigations and safety trends so that comprehensive safety performance information becomes readily available. The U.S. Coast Guard should assign a high priority to data compatibility and sharing across existing and future marine safety data bases and should develop a sound methodology to enable comparison of safety data currently maintained in incompatible data bases.

HUMAN SYSTEMS

Professional Development

Professional development programs for mariners and marine pilots need to be improved, and each individual's navigation and piloting knowledge and skills need to be periodically refreshed, upgraded, and confirmed. Professional weaknesses and problems need to be identified and corrected before they become causal factors in marine accidents. After-the-fact official discipline, while an important tool, is only effective if it also leads to remedial action.

Marine professional development programs are not generally assessed for their effectiveness. There is no official oversight in the development and validation of practical skills in federal marine licensing for masters, mates, and pilots, except for radar observer certification. For state-licensed marine pilots, the development process varies among pilot systems but is primarily supervised by licensed pilots. There are no certification programs for navigation and piloting instructors or for marine licensing examiners to establish their professional and educational capabilities for guiding pilot development. Continuing professional development has not been guided by specific requirements or standards, notwithstanding growing efforts by some marine pilot organizations and shipping and towing companies to provide refresher and advanced training.

The rapid evolution and introduction of advanced electronic navigation and piloting technology create new knowledge and skill requirements, expanding the range of expertise required for effective operator performance. But the professional training base for mariners is not keeping pace with these changes. From a technical perspective, it is premature for U.S. training facilities to make major investments in advanced navigation aids until International Maritime Organization (IMO) standards for Electronic Chart Display and Information Systems (ECDIS) are finalized, other IMO equipment standards updated, and equip ment is manufactured to them. Selective investment in advanced electronic charting systems meeting the IMO's provisional ECDIS standards may, however, be appropriate and necessary to aid in familiarizing mariners with these new systems. Near-term changes made in training facility resources will also need to be capable of incorporating revisions in IMO's Standards for Training, Certification, and Watchkeeping (STCW) when these revisions are finalized and implemented.

Approaches to development of theoretical knowledge and entry-level navigation and piloting skills range from accredited undergraduate programs at maritime academies to on-the-job training in the shipping and towing industries, in ferry operation, and often in marine piloting. To build expert qualifications, marine pilots need a basic knowledge of nautical theory, practical navigation skills, local area knowledge, broad-based shiphandling skills, and progressive advancement on routes and categories of ships. Shipboard responsibilities often do not allow masters and bridge teams to develop proficiency in piloting skills, shiphandling, and local knowledge.

There are few checks and balances within the marine navigation and piloting system, either human- or technology-based, for advance detection and correction of problems in the professional competence or performance of mariners, including marine pilots. Few masters, mates, or pilots have been formally trained, such as through simulation exercises, to process information and make decisions in extreme situations that require spontaneous emergency shiphandling and communications. However, marine pilots may develop sufficient experience to react correctly through their apprenticeships and service.

A consistent and thorough approach to professional development is needed. The core of a complete professional development program should involve:

- training and performance standards for professional mariners;
- accreditation of curricula and certification of instructors;
- development and validation of professional knowledge (theoretical and applied) and practical skills;
- development of special skills such as emergency decision-making and shiphandling;
- continuing professional development; and
- periodic requalification.

The committee's conclusions and recommendations concerning the professional development of individuals piloting ships and towing vessels and barges are consolidated in the section entitled *Marine Pilotage*. Recommendations regarding the professional development of mariners other than those piloting vessels involve economic, marine training, and education issues which were beyond the scope of this assessment. Training needs with respect to advances in technology are presented below.

RECOMMENDATION 4: Training programs should be developed concurrently with the voluntary or mandatory introduction of new navigation and piloting technologies. Bridge personnel should be trained in the use of these new technologies, and associated changes should be made in organizational relationships before the equipment is applied to operations; these efforts are essential to ensure the effective and prudent use of this equipment consistent with safety needs and requirements. Continuing training should be available thereafter, as necessary, to maintain mariner proficiency and to train new operators. To aid in the use of new navigation and piloting technologies in pilotage waters, provisions should also be made to familiarize marine pilots with the capabilities and general use of these technologies. The U.S. Coast Guard should encourage the International Maritime Organization to adopt standard training procedures for the use of new navigation and piloting technology. (See also recommendations 7–8, 10–11, 15–18, 21, and 24.)

Marine Simulation

Decade-old marine simulation research expanded fundamental knowledge about human factors. But this information base is incomplete and did not fully verify how well training results transfer to actual operations. Meanwhile, training needs have expanded because of the ongoing rapid evolution of navigation and piloting technology, ship's systems, and operating practices. The simulation research literature needs to be updated to reflect current conditions within the marine industry and piloting profession. However, there is a sufficient basis to believe that computer-based and manned-model simulations can, in varying degrees

- help individuals understand the limits of their knowledge and skills before these factors become an issue in actual performance;
- demonstrate ship maneuvering theory; and
- assist in developing or refining basic, advanced, and emergency shiphandling and bridge team management skills.

Marine simulation potentially can provide a general capability for validating skills and operational decisions without the risk that would be associated with similar efforts aboard real vessels. However, there are unresolved questions about:

- the accuracy of simulations for vessel operations in shallow and confined waters, especially where there are small under-keel clearances;
- how well simulation training experience transfers to actual operations;
- cost-effectiveness;

- the basis for establishing the equivalency or relevance of marine simulation to sea service for licensing purposes;
- the relative value of computer-based and manned physical scale-model simulations for various functions and operations;
- validation of simulations;
- accreditation of simulators and simulations;
- training and certification of instructors;
- evaluation of trainee performance; and
- the high cost of the technology per individual trained (these costs could be especially burdensome if borne by individuals rather than operating companies or licensing agencies, which is a major issue in the use of simulation in licensing).

These issues, which are vital to improving the value of marine simulation in professional development, need to be resolved before simulation is broadly applied in marine licensing or required for the licensing of marine pilots. Still, there is growing acceptance of marine simulation to selectively supplement, but not replace, more traditional means for the initial and continuing professional development of marine pilots. Simulations designed to improve shiphandling skills and to expose pilots to situations or vessels not routinely encountered can be especially useful if limitations in the simulation are clearly understood and conveyed to those trained. In this regard, marine pilots generally seem capable of making effective use of computer-based and manned-model simulations to refine generic and vessel-specific shiphandling skills.

RECOMMENDATION 5: The U.S. Coast Guard and Maritime Administration should update and build on their earlier assessments of marine simulation to determine the technology's capability and suitability for use in the initial training and qualification of pilots, in the continuing development of pilot skills in handling large vessels or complex operations, and for marine licensing purposes.

RECOMMENDATION 6: Marine pilot licensing authorities and marine pilot associations should encourage the selective use of marine simulation as one approach for meeting continuing professional development needs.

MARINE PILOTAGE

Debates over the safety performance of federally-licensed or state-licensed pilots, especially over which of these categories of pilots has a better safety record, have generated considerable public attention but miss the mark. The pilotage services provided by independent state-licensed and federally-licensed pilots routinely exhibit professionalism and competence. The real issue is that the national structure of marine pilotage and its administration, both federal and state, do not consistently ensure the completeness of professional development and adequate safety performance. Measures need to be improved to ensure the completeness of professional qualification and to identify for correction any training deficits and degradations in knowledge and skills that may occur after training or receipt of a license prior to any performance-related weaknesses becoming causal factors in marine accidents. The conclusions and recommendations that follow are designed to preserve and build on the strengths of key features found in the existing marine pilotage systems. The division of pilotage responsibilities between federal and state pilotage authorities would continue to be the centerpiece of pilotage nationwide, with certain refinements to achieve systemic improvements.

Safety Performance

The Committee on Advances in Navigation and Piloting found no statistical evidence that professional competence varies according to the methodology used to train independent marine pilots nor was any statistical evidence found that the performance of pilots varies by the level or type of maritime expertise acquired prior to entering the pilot profession. There is some anecdotal evidence from experts that differences in professional backgrounds can affect the time required for pilot candidates to adapt to various aspects of marine pilotage. While the length of time required to qualify as a pilot may vary as a result, comparable levels of professional skill can be achieved, provided that individual strengths and weaknesses are accommodated in professional development.

It is difficult to determine whether system-wide problems exist in marine pilotage, primarily because there is no standardized method for normalizing and ranking casualty data to support such determinations. The existing casualty data do not completely reflect the overall nature of safety problems in any one port area. There is also a general lack of understanding of the complexity of the port, waterway, and river operating environments; the nature and variability of risk factors that are present; and vessel behavior in shallow water and confined, asymmetrical channels.

Careful and statistically valid assessments of safety performance will be important and should reflect substantial differences in marine safety, risk, and exposure, even within the same port and waterway complex. The committee reviewed and assessed available studies and research that examined the safety records of pilots. This literature provided general background, but because of questions regarding the data utilized, how it was manipulated, and how measures of safety and performance were constructed, no sound inferences could be drawn.

The committee found no empirical evidence that safety performance varied by licensing authority. Nor was there evidence proving any difference in navigational safety between marine pilots and docking masters or between the pilotage of ships and of towing industry vessels. This is not to say that studies supporting particular points of view on these subjects could not be found; on the contrary, the committee reviewed several studies on each subject (Appendix D). However, the committee found no statistically sound basis that would indicate differences in performance among the various categories of federally- and state-licensed mariners who are providing pilotage services. At the same time, the committee heard considerable anecdotal testimony from representatives of all segments of the marine community offering ample evidence of a loosely integrated system with opportunities for error and incomplete measures for error detection and correction.

Pilotage Administration and System Standards

Pilotage regimes in the United States exhibit large differences in their administration. Considerable professional attention is given to pilotage administration in most systems to satisfy user needs, although performance guidelines and standards to meet official requirements are often informal.

Depending on the vessel's flag and the trade in which it is engaged, it might be piloted by an individual holding a state license, a federal pilot's license, or a federal pilot's endorsement to a master or mate's license. In each of these situations, the pilot is subject to different qualifications and to either federal or state authorities. For some intraport movements, there is no official pilotage requirement for foreign trade vessels, although the Coast Guard has proposed rules to begin closing these pilotage gaps.

Pilotage administration in the United States needs to be improved, with the objective of providing a consistent approach to ensuring marine safety and environmental protection. The core of an improved system would involve:

- professional standards for all aspects of piloting and pilotage administration;
- administration of standards through existing licensing/administrative bodies;
- consolidation of pilotage administration at the port or regional level; and
- accreditation of local programs.

The recommendations that follow are related to features that the committee concludes are essential for a complete pilotage system (see Appendix E). Some of these features are already embedded in the professional development programs or approaches used by most marine pilot and docking master associations and major U.S.-operating companies. Because the recommended systemic improvements are based on the strengths found in many existing port-level pilotage systems, it is anticipated that such systems would be able to satisfy the guidelines and standards that are envisioned by publishing existing processes and procedures and by implementing selective improvements in features that may not have previously received complete attention.

RECOMMENDATION 7: Nationally accepted baseline standards and guidelines should be established without delay in the following critical areas for state and federal pilot development, licensing, and administration, and to enhance pilot proficiency:

- ***PILOT TRAINING***

— ***Standards should be developed for training both state-licensed and federally-licensed pilots, including any individuals that may be authorized to act as pilots under local, state, or federal regulations.***

— ***Professional development should be supervised by pilot instructors qualified for this purpose. Qualification criteria or programs for pilot instructors should also be established.***

— ***Training for decision-making in emergency conditions should be a required element of pilot training.***

— ***Programs should be developed for continuing professional development and for periodic evaluation of all those who perform under pilot licenses, endorsements, or other official credentials.***

— ***Adequate requirements for recency of service or training should be established as prerequisites for the exercise and renewal of pilot licenses, endorsements, or other official credentials.***

- ***QUALIFICATION***

— ***Standards should be developed to qualify individuals to pilot particular types of vessels and routes.***

— ***Professional competence of prospective pilots should be determined through an assessment program involving qualified assessors, and should be based on observed performance as well as examinations. Qualification programs for pilot assessors should also be established.***

- ***PILOTAGE BOARDS***

— ***The provisions of state and local laws relating to pilotage boards should be reviewed and strengthened, if necessary, as it relates to their staffs, proceedings, composition, and accountability.***

— ***Members of pilot boards and commissions should be appointed by and accountable to state or local governing authorities.***

— ***Membership should be balanced, with adequate representation of state pilot groups, vessel operators, others in the maritime industries, and the public.***

— ***Boards should meet regularly and frequently. They should have adequate staff and other resources to administer pilotage and to conduct investigations. Their proceedings should be recorded and open, and they should publish their reports.***

- ***INVESTIGATION OF CASUALTIES INVOLVING PILOT PERFORMANCE.***

Issues of pilot performance as contributing or causal factors in marine casualties and incidents should be investigated promptly and completely by pilot boards and other

responsible authorities following standards and procedures developed for this purpose to guide individual and systemic corrective measures. Investigations should be objective, effective, and timely. The results should be made available in a public report. (See also recommendation 3.)

- ***GAPS IN COVERAGE***

— ***Standards of coverage are needed to ensure that all ships, regardless of flag, trade, or service, unless specifically exempted, are directed and controlled by an individual holding a valid state-issued marine pilot's license or a Federal First Class Pilot's License or Endorsement.***

— ***The standards should be specifically designed to fill existing gaps in state and federal pilotage requirements to ensure that there is official accountability for docking and mooring masters and for persons who direct in-port vessel movements. (See also recommendation 19.)***

Pilotage System Development and Oversight

The following recommendations offer an approach for pilotage that the Committee on Advances in Navigation and Piloting believes would enhance safety as well as the national-level credibility and accountability of local pilotage systems. The objective is to establish, for each port, a consolidated pilotage system that is subject to nationally acceptable and applicable standards and guidelines and which satisfies federal and state marine safety interests. At the same time, the recommendations are intended to preserve, enhance, and rely on strong local control of port-level pilotage systems.

Under the supervisory and administrative umbrella of state authorities, professions in the United States generally have been allowed to regulate themselves to some degree. State regulation of pilotage for vessels in foreign trade generally follows this model. Another characteristic of state pilotage is a large measure of port-level control. The federal system, which has filled important needs for coastwise vessels, has not ensured quality control for the professional development of federal pilots or docking masters, nor has it routinely monitored the provision of pilotage services, leaving this aspect of federal pilotage largely self-regulated. Port-region control is exercised by a regional Coast Guard official, but this official has little flexibility to modify pilot qualification requirements to address experience or skills necessitated by unique local operating conditions.

The committee reached a consensus on the need for standards of the profession, system accountability, and for a national commission to guide systemic improvements. There are, however, alternate views on the path to implement the national commission concept. One view is that safety performance in the marine community is substantially better than suggested by spectacular marine accidents, and that the piloting profession, leading shipping and towing companies, and unions are already responding vigorously and positively to public calls for improvements in the piloting performance of members and employees. This school of thought opines that professional standards and accreditation programs will result from such industry- and piloting profession-based initiatives to improve professional development and performance, that the necessary expertise is readily available within the marine community to guide these efforts, and that the existing federal and state pilotage systems would be adequate with certain improvements guided by an advisory commission. Another view is that more rigorous pilotage and system standards should be established and system accountability reinforced without delay by either a new federal entity, if it can be activated quickly, or if not, then by the Department of Transportation using existing departmental resources. The central view of the committee is that the guidance of systemic improvements needs to be elevated above local and regional influences and be independent of existing regulatory bodies. It is believed that this can best be accomplished through the establishment of an independent, professionally credible national authority to develop and implement professional standards and an accreditation process that would both motivate and assist existing federal and state pilotage administrators in refining and enhancing their pilotage systems while also promoting system accountability.

Local organizations have demonstrated substantial capability to provide the expertise and interorganizational working relationships needed to guide marine traffic regulation at the port level. These organizations include, in some ports, officially characterized and informal advisory committees, composed of marine pilots, docking masters, shipping and towing industry interests, the public, and the Coast Guard. In several ports, voluntary vessel traffic management services administered by marine pilots implement agreements for this purpose among representatives of the local marine communities. To ensure a credible marine navigation and piloting system, local efforts such as these should be expanded regionally and nationally to bring all interested and affected segments of the maritime community and the public together. In particular, there is a great need to motivate and sustain a spirit of cooperation in providing a more facile and effective approach to pilotage administration and, as discussed later, marine traffic regulation. A national interdisciplinary organization should be formed that has the necessary resources, professional expertise, and credibility to guide the entire system. Consultative relationships are needed at the port level to guide area-specific improvements according to national standards and guidelines.

The Coast Guard should represent federal interests in national and port-level improvements to the marine navigation and piloting system because of the agency's marine and environmental safety responsibilities and its national regulatory infrastructure. However, the Coast Guard will need to draw on the maritime community to augment the expertise needed to improve the marine navigation and piloting system with respect to Coast Guard missions and responsibilities.

RECOMMENDATION 8: An independent national commission should be established to guide and assist pilotage and marine safety authorities in

implementing systemic improvements with respect to professional standards and accreditation programs for pilotage, navigation, and waterway safety. The duties of the commission would be to:

- ***develop national standards and guidelines for marine pilotage and marine traffic regulation (see recommendation 7);***
- ***develop and administer procedures and criteria for the accreditation of federal, state, and local pilotage systems and marine traffic regulation systems in accordance with the commission's national standards and guidelines;***
- ***define, promote, and assist with the steps necessary to achieve a consolidated port-level system of pilotage; and***
- ***provide expert advice to marine pilotage authorities and the Coast Guard on matters of marine pilotage and marine traffic regulation***.

Action to establish a national commission could be initiated by the piloting profession. The exact nature and form of the commission would depend to a large extent on the results of the piloting profession's initiatives to improve professional development, piloting practices, and system accountability. The existing pilotage infrastructure should participate in the formation of the commission. But, for the broad credibility that would be needed to guide the pilotage system changes recommended in this report, the national commission should have a charter from Congress.

The American Pilots' Association and other professional organizations representing the professional interests of federally-licensed and state-licensed pilots should examine the feasibility of establishing accreditation processes and standards for pilot and docking master professional development programs as a means of ensuring competence and proficiency and to improve public confidence in pilotage. To the degree that standards and accreditation processes developed by the piloting profession satisfy safety objectives, they could be adopted as national standards by the commission.

Performance review of the national commission should be conducted periodically to determine that the commission is meeting goals and objectives established for it.

A national commission concept has been suggested before for marine pilotage, but never attempted for either marine pilotage or marine traffic regulation. In order for the concept to work, considerable implementation analysis beyond the scope of this report will be necessary to ensure that the integrity of pilotage services is not adversely affected and that the concerns of all the interested parties are addressed. In particular, goals and objectives, commission membership, leadership, accountability, administrative location, official status, subject matter expertise, and staff support will be important to success. Careful attention in each of these areas and effective, impartial performance by the commission will also be needed to establish concept and commission credibility with the federal and state governments, marine community, and the public.

The commission should be expected by Congress, the federal and state governments, the marine community, and the public to progressively improve professional regulation of pilotage and marine traffic regulation in consultation and cooperation with the marine community and marine regulators, as envisioned in recommendations 7 through 19, 21, and 24. With respect to the commission's accreditation role, the committee envisions a concept similar to accreditation of college and university programs that are designed to prepare individuals for professional careers. The commission would oversee an accreditation process. Accreditation would be designed to ascertain that pilotage and marine traffic regulation systems conform to national standards and contain the features needed in sufficient measure to satisfy federal, state, local, piloting profession, and shipping and towing industry marine safety needs. Commission oversight responsibility would also include periodic program review to renew the accreditation of each system and to identify needed improvements for pilotage authority action.

In order to serve national interests in marine safety, commission membership needs to be carefully composed to assure balance and fair treatment as well as sufficiency of subject matter expertise. The commission should be relatively small, about 5 to 7 members, in order to facilitate decision-making. The commission's membership should nevertheless be capable of effectively addressing the interests of the federal and state governments, the marine community (including shipping and towing industry companies, marine pilots, and port authorities), merchant mariners, and the public. Each individual selected to serve needs to be capable of impartial and credible service.

The commission should be independent. It should be adequately staffed by individuals with professional expertise necessary to support commission responsibilities. The Congressional charter for the commission should make clear that neither federal nor state-level pilotage jurisdictions are preempted initially or upon implementation of a port-level system of pilotage for ships (recommendations 10-12). However, the roles and responsibilities of pilotage authorities would be refined as nationally acceptable and applicable standards and guidelines are developed and pilotage systems are accredited to them.

National standards and guidelines must be sufficiently flexible to accommodate substantial variations in the form of pilotage administration as well as pilot development programs and requirements needed to prepare and maintain individual capabilities for effective service in unique local operating environments. Commission success in developing nationally accepted standards for marine pilotage and marine traffic regulation would be necessary prior to proceeding with a consolidation of pilotage into single systems at the port level.

RECOMMENDATION 9: Acting under the authority of the Federal Advisory Committee Act or other appropriate enabling authority, the Secretary of Transportation should convene in each port or port region a federal navigation and piloting safety advisory committee (or designate an existing advisory body where one exists). The local advisory bodies should provide expertise in support of pilotage administration and marine traffic regulation for that port.

A federal advisory committee normally advises its sponsoring federal agency. Given the cross-cutting nature of navigation, piloting, and marine traffic regulation interests and responsibilities, the potential exists for marine advisory committees to serve the marine community at large with the Coast Guard providing a secretariat function in support of this objective.

Duties of local advisory committees should include review for consistency with national standards of pilot development and licensing rules and related requirements applicable to each port. Advisory committees should propose measures to fill any gaps that may exist in official accountability of pilotage for their port or region. They should also advise on marine traffic regulation measures needed to improve order, predictability, and safety within their port or region. The advisory committees should be empowered to make recommendations to the marine community and to state and federal officials on means to achieve higher standards, their consistent application nationwide, and on filling gaps in waterways management and pilotage. Membership on the local advisory committees should represent: port, pilot, and marine industry interests; local, state, and federal government interests; and the public interest.

Strengthening Pilotage Administration

The distinction between foreign and coastwise trade in determining pilotage jurisdiction results in dual pilotage administration with varying requirements for pilot qualifications that apply to the same vessels over the same routes. Because of gaps in pilotage requirements, foreign-flag and U.S.-flag vessels in foreign trade can be moved without a licensed pilot aboard or can be piloted by a licensed pilot who is not performing under the authority of a federal or state license or by a person who does not hold a pilot's license. The recommendations for a national commission, local advisory groups, and measures to improve official accountability (see recommendations 7 through 10, and 15 through 19) will, over time, result in a new synergism between state and federal interests that, in turn, will improve pilot development and performance. The coordination and consolidation that should result will enhance all aspects of marine pilot performance and will provide a common foundation of pilot knowledge, skills, and procedures needed to ensure a consistent and reliable operational first line of defense against individual substandard ships and crews.

As a general rule, current state requirements governing the professional competence of pilots are higher and more complete than are federal pilotage requirements when both regimes are compared with the features of a complete pilotage model (see Appendix E). It should be a national objective to consolidate ship pilotage under a single system in and for each port.

Recommendations 7, 8, and 9 represent a consolidated approach and must be implemented at the same time as a group rather than singly; this is necessary to achieve the most effective remedy to needs in the marine navigation and piloting system. The same consolidated approach is represented with recommendations 10, 11, and 12, which also must be implemented all together. Finally, the order in which the recommendations are implemented is important: recommendations 10, 11, and 12 should be implemented only after recommendations 7, 8, and 9 have been implemented so as to ensure that the elements necessary for an effective single marine pilotage system in the United States (a national commission, national standards and guidelines, and port-level pilotage authorities and advisory committees) are in place and functioning to expectations prior to implementation of a nationwide pilotage system.

RECOMMENDATION 10: A single marine pilotage system should be established for each port and waterway system. The system should be guided by national standards designed to satisfy nationwide interests. The pilotage system should be accredited nationally but overseen locally by a nonfederal public organization with balanced membership representing state, pilot, marine industry, and public interests and with authority to shape pilotage rules to meet regional and local needs. In order to establish broad-based credibility, the following conditions must be met before pilotage in a port is consolidated into a single system:

- ***national standards (recommendation 7) need to be in place;***
- ***national standards need to be met in the port (see recommendations 7 and 16); and***
- ***the consolidated local program should be accredited under the authority and procedures of the national commission (recommendation 8)***.

An own-ship pilotage option for U.S.-flag ships can be sustained for those masters and mates who qualify for this high level of trust and confidence. Accountability and official oversight can be effectively achieved for this option through the combined effects of U.S.-flag-state authority, U.S. port-state control, and improvements recommended in this report to improve pilot professional development, performance, and accountability to pilotage authorities.

RECOMMENDATION 11: Masters and mates of U.S.-flag ships, regardless of whether the ship is sailing in coastwise or foreign trade, should have the

opportunity to qualify for route-specific and vessel-specific pilotage credentials, federal or state, authorizing them to pilot the vessels on which they serve. (Under the port-level system of recommendation 10, these provisions would be administered on a port-specific basis by the local pilotage authority.) (See recommendation 18.)

RECOMMENDATION 12: The federal requirements for a First Class Pilot's License should be converted into a national process for entry-level certification, which should be a prerequisite for further pilot training. This national certification process should be administered by the U.S. Coast Guard.

Pilotage in the Coastwise Towing Industry

Although there is a scarcity of empirical data for assessing the safety of navigation and piloting, it appears that pilotage in the coastwise towing industry is generally safe and effective. (Pilotage conclusions and recommendations for the inland towing industry are outside the scope of the committee's assessment.)

RECOMMENDATION 13: The U.S. Coast Guard should collect empirical data that are needed to assess the effectiveness and safety of navigation and piloting in general, with attention to improving the empirical data relevant to the pilotage of coastwise towing vessels. The U.S. Coast Guard should periodically use these data to evaluate program effectiveness.

In the committee's judgment, the safety of the entire piloting system would be significantly enhanced by strengthening the practice and administration of piloting in the towing industry in the following ways:

RECOMMENDATION 14: Pilotage in the coastwise towing industry should be considered a part of the fabric of the national port-level system, with qualification requirements guided by the standards and guidelines developed by the national commission. (See recommendations 7 and 18.) However, official oversight of pilotage in the towing industry, including pilot licensing, should remain under the jurisdiction of the U.S. Coast Guard.

RECOMMENDATION 15: Administration of and standards for licensed masters, mates, and operators who "act as" pilots of coastwise barges should be strengthened as follows:

- ***Consistent with the development of national standards for pilot training and performance, the U.S. Coast Guard should strengthen applicable licensing requirements and standards for those who "act as" pilots. Requirements that should be***

strengthened include the amount and recency of experience in the actual handling and navigation of towing vessels and barges under varying conditions on specific routes.

- ***The U.S. Coast Guard should establish administrative requirements to ensure, and provide evidence of, compliance with the requirements and standards. The Coast Guard should also periodically audit pilotage in the coastwise towing industry.***
- ***The American Waterways Operators and other professional organizations representing the professional interests of the towing industry should examine the feasibility of establishing an industry-sponsored accredited training program as a means to ensure operator competence and to improve the credibility of professional development within the towing industry.***

Transition Issues

The transition from the present pilotage system to a nationally consistent port-level system characterized by local consolidation and administration will not be easy. The following recommendations address specific concerns that are certain to arise.

RECOMMENDATION 16: All pilotage authorities should, pending development of national standards, examine pilotage under their jurisdiction and make improvements guided by the concepts advanced in recommendation 7. In particular, the U.S. Coast Guard should improve the quality of piloting conducted under the authority of a Federal First Class Pilot's License or Endorsement. Steps should be taken by all pilotage authorities to:

- ***increase requirements for supervised training and development of professional skills;***
- ***validate professional competency and skill at the time of initial licensing and license renewal; and***
- ***periodically assess the performance of marine pilots, docking masters, and mooring masters.***

RECOMMENDATION 17: The Federal First Class Pilot's License, pending establishment of a single marine pilotage system (see recommendations 10 and 12), should be reserved for individuals who have demonstrated the substantial knowledge and skills necessary to perform effectively as independent marine pilots for the categories of vessels and routes they may be called on to serve. Route extensions should be permitted through endorsements to the license. Independent federal marine pilots affiliated with existing federal pilot associations and docking masters affiliated with existing docking master associations that are not under state pilotage administration (see recommendation 19) should be consolidated into the port-level pilotage system as it is established, subject to guidelines established for this purpose by the national commission (see recommendations 7 and 8). Individuals affiliated

with any other organization of independent federal marine pilots or docking masters that might operate in the future before consolidation occurs should be assessed by the national commission to determine their legitimacy.

RECOMMENDATION 18: Except as provided for by recommendation 17, all other federal pilotage credentials for U.S.-flag vessels should be limited to endorsements on U.S. merchant marine licenses as masters, mates, or vessel operators. Endorsements should be specific to vessel type, size, and route. (See recommendation 11.)

- ***Requirements for recency of navigation experience on both vessel and route should be reviewed and, if necessary, strengthened, to ensure sufficiency for the intended service. This review should recognize expertise acquired through general maritime service as well as vesseland route-specific experience.***
- ***The goal should be to establish license endorsements as a means to implement a program that would permit masters and mates of U.S.-flag ships to serve as pilots for their ships, provided that they maintain high standards of training, experience, and performance through service on the specific vessels and routes covered by their pilotage credentials.***
- ***On establishment of the consolidated local pilotage system, the federal pilotage endorsement should serve as an entry-level requirements for obtaining a credential issued by the local pilotage authority for own-ship pilotage of U.S.-flag vessels.***

RECOMMENDATION 19: Steps should be taken immediately to close all gaps in the current system of pilotage administration so that all foreign trade vessels are piloted by individuals who are officially accountable to a pilotage licensing authority. Specific gaps that need to be closed involve:

- ***docking, undocking, and mooring services in ports and waterways and for offshore platforms and buoy systems within existing pilotage jurisdictions where these services are not subject to official accountability through federal, state, or local pilotage requirements; and***
- ***movements of vessels to, from, or within any port where official accountability is not established by federal, state, or local pilotage requirements.***

In the absence of state action to close these gaps in official accountability within a reasonable time (12 months) for vessels within state pilotage jurisdiction, the federal government should take direct action under existing authority. Where gaps in official accountability exist for pilotage provided to vessels in U.S. waters that are not subject to state jurisdiction (e.g., mooring a ship to offshore facilities outside of a state's seaward boundary), the federal government should take immediate action under its existing authorities or, where necessary, seek enabling legislation from Congress to permit establishment of official ac countability. Coast Guard action already in progress to close gaps in some pilotage waters should continue.

Ship masters and senior mates serving permanently aboard the same vessel or sister vessel on regular routes can under these select conditions potentially become more familiar with their vessel's behavior than a marine pilot, although the pilot would have more extensive local knowledge. Therefore, there should be provisions so that the master of a foreign-flag ship (or another suitably qualified ship's officer performing under the master's direct supervision) could perform docking evolutions in the immediate vicinity of the pier or berth, as long as the vessel is subject to a U.S. pilotage authority and a marine pilot accountable to that authority is present to provide advice on local conditions. (Docking by masters of U.S.-flag ships is covered in recommendation 11.)

WATERWAYS MANAGEMENT

Just as comparing the safety performance of various pilot groups is not the core issue, neither is comparison of safety performance among ports. The real issue is that the national structure for waterways management does not guarantee consistent and adequate administration, marine traffic regulation, and safety performance.

Management of U.S. ports and waterways is loosely integrated, with substantial opportunity for operational problems to develop and go undetected until an accident occurs. At present, no one authority has comprehensive responsibility to ensure that the marine navigation and piloting system works efficiently and effectively. National policy does not guide determination of what level of safety is acceptable, nor do consistent standards guide system administration or safety performance.

Substantial variations among ports in the nature and level of exposure and in safety data collected have not been normalized using a standard methodology that accounts for all key exposure variables affecting operational risk. Therefore, the number of casualties, or casualty rates normalized for only one or two exposure variables, do not necessarily reveal whether a given port is any more or less safe than any other. Local tolerances for operational risk vary among ports and waterways and often are influenced by tradeoffs between safety and economic efficiency.

Foreign ships constitute about 90 percent of oceangoing ship traffic in U.S. waters. This is an important factor in view of evidence of inadequate attention to international construction and maintenance standards by some classification societies, a perceived gradual erosion in the development and maintenance of professional qualifications involving some ships of some flag states, growing recruitment of crew members from nontraditional sources, and aging merchant fleets.

Many channels that support coastal and international trade are obsolete rela tive to the size and maneuvering behavior of modern ships. Once a channel is built, it is rarely operated to conform to its designed capacity or formally evaluated to determine safe operating parameters that, if followed, would permit safe passage by ships that exceed design criteria.

To deal with these issues, increased attention should be devoted to performance monitoring; surveillance; enforcement of shipping laws; and management of waterways systems, including regulation of marine traffic. Also, improved coordination and cooperation is needed among state and federal regulators, maritime interests, and the affected public to provide the expertise and perspectives needed to balance safety and economic interests. Local advisory bodies should be established to achieve improved coordination. (See recommendation 9.)

Enforcement of Shipping Laws and Regulations

There are sufficient indications of substandard maintenance and manning practices on the ships of some flag-states to substantiate the need for strong U.S. action to redress vessel-specific substandard conditions and operating practices and to stimulate international corrective action through the International Maritime Organization. The Coast Guard's enforcement of existing international standards and national shipping laws and regulations is essential to the protection of U.S. navigable waters, ports, the public, and the environment. If international measures to rectify substandard operating practices prove ineffective or untimely, then unilateral imposition of additional national requirements may be necessary. Documentation of substandard conditions is essential as a basis for determining whether additional equipment and manning, appropriately guided by technical and performance criteria, should be required as preconditions for operating in U.S. waters.

Legislation on the limited matters within the jurisdiction of U.S. coastal states directed to vessels in foreign trade could affect international negotiations and must be very carefully formulated and enacted to support national and international interests, as well as the interests of the U.S. coastal states. Marine pilotage requirements for foreign trade shipping, a state responsibility, need to meet high standards and be consistently applied (see recommendations 7 through 12 and 16 through 19). All these measures are essential to ensure that both federal and state marine and environmental safety interests are served and that marine pilots are adequately supported in their role as representatives of state and federal interests in ensuring safe navigation.

RECOMMENDATION 20: The U.S. Coast Guard, in consultation and coordination with the U.S. Customs Service and other appropriate federal agencies, should continue and augment its efforts to identify substandard vessels, regardless of flag. The U.S. Coast Guard and other appropriate federal agencies should take whatever action is indicated to bring each ves

sel trading in U.S. waters into compliance with applicable international standards and U.S. national requirements.

- ***The U.S. Coast Guard should, in consultation with appropriate federal agencies and national and local advisory bodies (recommendations 9 and 24), establish procedures for reporting observed or suspected substandard conditions or inadequately manned vessels that pose unacceptable operating risks to marine, public, or environmental safety. Data based on these reports should be routinely assessed, and remedial actions considered, if trends toward substandard maintenance and manning persist or increase.***
- ***Provisions should be made to improve cooperation among U.S. coastal states and the federal government in reducing risks involving foreign-flag shipping.***

Management of Waterways Systems

The loosely integrated management of U.S. waterways systems needs to be tightened in the face of regional and global economic competition and the safety and environmental concerns of the public and Congress. Centralized management by a single authority is not necessarily essential if components of the marine navigation and piloting system can be effectively and systematically coordinated through cooperative working relationships, agreements, and consultation.

The national airspace system is often referred to as an alternative model for the marine traffic regulation. The committee's comparison of air traffic control and marine traffic regulation found faults in this analogy because of significant differences between the two operating environments and the supporting institutions. There are, however, many features of the air traffic control model that could serve as long-term goals for an improved marine navigation and piloting system for ports or waterways and for approaches to pilot boarding areas. These include:

- a system-wide operating concept;
- high-reliability systems;
- universal procedures and protocols;
- universal operating language;
- instantaneous precision navigation capability;
- adherence to pre-planned routes;
- availability of real-time environmental data;
- vigorous training requirements for pilots and controllers;
- professional controller staff;
- technology-based decision aids; and
- a near-miss reporting system.

Most of these features would require widespread introduction of new operating procedures and highly advanced navigation technology, and are thus suited to international implementation. Nevertheless, the organizational structure for real-time, interdependent decision-making can be improved by implementing standard operating procedures and communications protocols in each U.S. port area. Vessel traffic services (VTS) operated by the federal government and VTS systems and VTS-like services, including information systems, operated by other entities should be expanded and improved to meet local safety, economic, and environmental protection needs.

Where VTS systems or VTS-like services are installed, the International Maritime Organization's VTS guidelines should serve as the minimum operating standard and should be augmented in the United States by national standards applicable to both federal or nonfederal VTS and VTS-like operations. All VTS systems and VTS-like operations should be accredited to these standards, to facilitate their use by vessels in foreign trade. The Coast Guard's substantial traffic regulation authority, which enable time and space management and direction of actions by specific vessels, could be more widely applied than it is now, especially where Coast Guard-operated VTS systems have been established. Expansion and improvement of marine traffic regulation, including installation of VTS systems, should be guided by consultations with national and local advisory bodies (see recommendations 9 and 21). Professional development of VTS operators should be enhanced to ensure adequate preparation for functional duties.

RECOMMENDATION 21: All VTS systems and VTS-like operations should be accredited to international and national operating and performance standards. Accreditation should be the responsibility of the national commission on pilotage, navigation, and waterway safety (recommendation 8). The commission, in consultation with the U.S. Coast Guard, should develop and promulgate national standards to guide interactions between VTS systems (and VTS-like services) and users and to guide improvements in services provided. Pending creation of the commission, interim measures should be promulgated by the U.S. Coast Guard in consultation with the Navigation Safety Advisory Committee.

RECOMMENDATION 22: Government and privately operated VTS systems and privately operated VTS-like services should be expanded and improved, as determined by safety, economic, and environmental protection needs, and as a means to improve the organizational structure for interdependent decision-making in ports and waterways and to protect against navigational errors in these waters. The Department of Transportation should take steps to define, promote, and implement measures to achieve this objective. Where feasible, VTS and VTS-like services and electronic surveillance should extend seaward of pilot boarding areas to protect against navigational and operational errors when approaching pilot waters.

RECOMMENDATION 23: The U.S. Coast Guard should operate VTS systems where federal authorities employ these systems to govern or influence vessel movements or maneuvering. Joint federal–private operation or cost sharing should also be considered for expanded VTS coverage, provided that suitable arrangements can be made for exercising federal authority where it is used in conducting VTS functions, such as in managing use of federal anchorages. All private operation of VTS-like services should be authorized by the Department of Transportation.

RECOMMENDATION 24: The U.S. Coast Guard should establish or authorize a national training course that meets national criteria for local VTS instructors, and an entry-level course for VTS operators, to improve the quality and consistency of VTS systems and VTS-like operations, and to facilitate implementation of national VTS standards.

Special Operational Considerations

Access to channels by vessels that exceed channel design parameters and special operating criteria guiding their transit should be decided by port safety authorities based on consideration of operational risk, in consultation with affected and interested parties, marine pilots, and local advisory bodies (recommendation 9). Use of marine simulation should be considered when resolving uncertainties about the safety of such transits or for building a consensus concerning special operating criteria.

RECOMMENDATION 25: When operations are proposed that present significant operational, environmental, or public health risk, they should be analyzed objectively to ensure that they can be performed safely. Special operational criteria should be set if needed to achieve levels of safety equivalent to that of routine vessel transits. These determinations should involve the U.S. Coast Guard, U.S. Army Corps of Engineers, and local advisory bodies. (See recommendation 9.)

NAVIGATION AND PILOTING TECHNOLOGY

Technology, along with training programs (recommendations 4 through 6, and recommendation 24) and organizational changes (recommendations 8 through 10, and 21 through 23), can be applied to mitigate human error and reduce operational risk in marine navigation and piloting. Emerging electronic, real-time positioning and charting technologies can offer several significant benefits: they can add precision to navigation, improve the clarity of information provided for decision-making, allow the user additional time to consider infor mation and alternatives, and may improve decision-making and the safety of navigation and piloting overall.

The emerging technologies require a shift from traditional human-intensive methods of navigation and piloting to new approaches incorporating both human and electronic elements, with the human assisted by the technology. However, the full prospective benefits of the new technologies, especially ECDIS, will not be gained in the near term unless measures are taken to:

- provide technical and operating standards for the new technologies;
- develop organizational strategies for introducing new technology, including user training and changes in operating practices designed to enhance the technology's contribution to safety (see also recommendation 4); and
- update laws, regulations, and policies that are based on the use of traditional methods and older technologies as standard practice.

The introduction of new technology may result in incompatibility among systems that combine old and new technology. Thus, the development and proliferation of new technology must be handled carefully; requirements may be warranted for modular or compatible development and retrofit of existing vessels, and they may need to be addressed. Policies and procedures based on older systems and traditional navigation and piloting practices also will need to be modified to facilitate the introduction of new technology without compromising the levels of safety and accountability inherent in existing practice.

The real-time, position-keeping benefits of advanced electronic navigation systems can be obtained through near-term installation of emerging and innovative electronic charting and precision navigation systems even though technical and operating standards need to be developed and implemented, legal issues resolved, and institutional impediments to their use removed. A concerted effort by vessel owners and operators and strong encouragement by marine safety authorities will probably be needed to accelerate the rapid introduction of advanced navigation technologies so that experience can be gained and mariner trust and confidence built in system capabilities through prudent use. Otherwise, it is likely that the integration of new technologies into routine operations and the potential benefits they offer to improve operational safety will proceed at a less rapid pace.

RECOMMENDATION 26: The U.S. Coast Guard should strongly encourage the development and updating of international technical and performance criteria for advanced navigation systems with the objective of providing a solid foundation for the systematic introduction of advanced navigation technologies and as a benchmark for national technical and performance criteria.

RECOMMENDATION 27: The U.S. Coast Guard and Maritime Administration should continue research directed at developing technical and operating standards for new technologies. Research and development for advanced marine navigation and piloting technology should be funded to a much greater extent than it is now. Furthermore, to obtain the maximum return on this investment, the U.S. Coast Guard, Maritime Administration, National Oceanic and Atmospheric Administration, and the U.S. Army Corps of Engineers should jointly develop research and development priorities based on risk assessments.

RECOMMENDATION 28: Laws and regulations addressing operational requirements for navigation and piloting technology should be based on performance objectives rather than equipment-based criteria so that effective use (and maximum benefit) of advanced navigation technologies and innovative research and development are not inadvertently constrained. The U.S. Coast Guard, Maritime Administration, National Oceanic and Atmospheric Administration, and U.S. Army Corps of Engineers should review existing laws, regulations, and policies to identify impediments to the development and introduction of promising navigation and piloting technologies. These agencies should recommend to Congress any changes to enabling legislation that may be indicated, and they should modify policies and regulations under their jurisdictions to the extent necessary.

RECOMMENDATION 29: The following steps should be taken to accelerate the introduction of advanced navigation technologies into marine operations:

- ***The introduction of advanced technology should occur as soon as practical, consistent with the development of a supporting infrastructure that permits its effective use. Training should be provided concurrently with the introduction of the technology (See also recommendation 4.)***
- ***Owners and operators of oceangoing vessels trading to U.S. ports, U.S. coastwise vessels, any other vessel subject to federal or state pilotage requirements should take the initiative to install electronic charting and precision navigation devices that are suitable for their applications and for navigation safety of their vessels. Owners and operators of inland towing vessels that operate in pilot waters should make a concerted effort to install equal or equivalent navigation devices as practical for each vessel's configuration and operation.***
- ***Mariners and pilots aboard vessels with new technologies should take the initiative to become familiar with these technologies and to learn how to use system capabilities. These technologies should be used carefully in conjunction with traditional navigation methods to ascertain the new technology's suitability and reliability for application in pilotage waters.***
- ***The U.S. Coast Guard should encourage the introduction, field evaluation, and use of advanced navigation technologies by owners, operators, and mariners through***

International Maritime Organization, national and local Department of Transportation-chartered advisory committees, and other media to which the agency has access (See also recommendation 9.)

Traditional Aids to Navigation

Mariners continue to rely heavily on traditional short-range aids to navigation, especially buoys and ranges. These traditional aids often lose their benefit when most needed, that is, during heavy sea conditions and low visibility. Continued efforts by the Coast Guard to improve the visibility of these aids are having positive effects, as are Coast Guard initiatives to advance the development and use of the Differential Global Positioning System (DGPS). But little effort is being made to develop improved voice radio communications capabilities, electronic data links, or electronic ranges such as localizer beams.

Navigational information needs are not satisfied by existing waterways management systems, including VTS systems. The reasons include inefficient communications and the uncertainty of VTS-users about VTS operator capabilities, especially where operators lack merchant marine or pilot licenses and provide maneuvering guidance. To meet information needs, locally operated navigation systems will appear in some locations that will likely include the use of interactive, portable communications, navigation, and surveillance systems (PCNS). When mature, these systems have the potential to provide essential information on navigation and instantaneous position data for direct interpretation by marine pilots regardless of the equipment installed aboard a vessel, with or without secondary safety oversight by shore-based personnel.

RECOMMENDATION 30: The U.S. Coast Guard should maintain, and when appropriate, enhance existing short-range aids to navigation that will support evolving technologies as well as traditional navigation technologies. In particular, the U.S. Coast Guard should continue efforts to improve visibility and electronic acquisition of buoys during adverse sea and weather conditions. The U.S. Coast Guard should also examine the feasibility of electronic ranges and distance-measuring equipment for specialized local use, which could be in the form of a local Differential Global Positioning System.

Navigation Systems

The Differential Global Positioning System (DGPS), when combined with ECDIS and when fully operational, will provide a substantial technological capability for enhancing operational safety. Such a system will provide nearly instantaneous, accurate positioning information; steering guidance; and automatic hazard warnings. This technology has the potential to provide a more accurate and reliable automatic radar plotting aid function if it is integrated into periodic broadcasts (automated dependent surveillance) of individual vessel position and velocity.

An electronic charting system is the central feature of emerging onboard navigation systems. The effective use of electronic charting systems for real-time precision navigation depends on the completion and proper operation of DGPS. Completion of DGPS and development of a long-term commitment to maintain and operate it are critical to obtaining the potential benefits. Immediate and long-term measures must be taken by the Department of Defense and the Department of Transportation (through the Coast Guard) to achieve this objective.

Electronic charting systems, consisting of at least an electronic chart and real-time position data, and which meet legal requirements for navigation, will be the next type of navigation technology that has the potential to achieve universal commercial use, following the example of radar and very high frequency radio. The capability to obtain instantaneous precision positioning information and display it on an electronic chart without loss of geographic detail due to weather and sea conditions, will constitute a great advance in navigation systems and will significantly improve navigational safety.

RECOMMENDATION 31: The Department of Defense should fully establish the Global Positioning System at the earliest opportunity, and the Department of Transportation, through the U.S. Coast Guard, should accelerate establishment of Differential Global Positioning System for marine navigation in U.S. navigable waters and the seaward approaches. The Department of Defense and the Department of Transportation should develop a plan and make a long-term commitment for the continued maintenance and operation of these systems.

Modern hydrographic data coverage is inadequate for much of the nation's coastal waters. Mariners are notified of critical corrections to charts through weekly Coast Guard publications; required changes to charts aboard ship are done manually, if at all. New editions of charts with these corrections are not published by the National Oceanic and Atmospheric Administration until a substantial number of critical corrections are accumulated. Publication of updated charts is constrained by a substantial backlog of reported but unsubstantiated discrepancies, and there are no operational risk analyses to guide prioritization of discrepancy correction. The result is chart data that are substantially less precise than what is technologically achievable. Legal issues concerning the electronic charting data and the legal standing of electronic charting systems are unresolved.

RECOMMENDATION 32: The National Ocean Survey of the National Oceanic and Atmospheric Administration should conduct modern and updated

surveys of all U.S. ports, waterways, and port approaches. Specifically, the Department of Commerce should obtain and allocate the necessary resources to assure the timely collection of hydrographic data that are essential to enhancing the effectiveness of passage planning and the safety of vessel operations.

RECOMMENDATION 33: The National Oceanic and Atmospheric Administration should accelerate digitization of hydrographic and topographic data essential for producing nautical charts electronically. The agency also should lead an effort to resolve the legal status of electronic charts, including those provided by other vendors using agency-digitized hydrographic data. The Department of Commerce should obtain and allocate the necessary resources to facilitate the introduction and use of electronic charting systems.

The integrated bridge concept may have potential to reduce operational risk through the consolidation of navigation, steering, planning, and communications functions at one workstation (as is done in aviation). Effective and reliable use of integrated bridge systems (IBS) has been demonstrated under very select conditions—on set routes where repeat transits are frequent and piloting is accomplished by permanently assigned mariners with expert piloting skills. These systems have not yet been proven effective for universal use in piloting although locally specific successes have been reported. Pilot uncertainty about the maneuvering behavior of unfamiliar ships and the pilot's general lack of familiarity with integrated bridge technology means that vessel- and route-specific validation will be necessary to establish IBS reliability for even regular routes. How an independent marine pilot would interact with IBS is not certain; full use of system capabilities seems to require either integration of independent marine pilots into the bridge team, a nontraditional role, or redefined working relationships between the pilot and the individual operating the IBS. Physical data relevant to maneuvering that are needed to support decision aids in integrated systems are limited. Real-time tide, current, and weather information is not available except in very select locations. Tide and current prediction tables, often derived from surveys conducted decades ago, need to be updated in the near term.

The integrated ship control system (ISCS) may provide a means to reduce crew size and reduce human error in the performance of some navigational tasks. Piloting expert systems and other decision aids may be needed to enhance or facilitate operator use of automated systems. As hands-on experience is reduced through automation, additional professional training may be required to prepare vessel operators to determine when integrated systems are not performing within tolerances and to build skills for taking corrective action. While ISCS may be satisfactory for at sea operations, reduction of bridge team size because of ISCS installation would reduce the onboard resources for traditional navigation meth ods, including hand steering. These traditional methods may be needed at times, especially during operating conditions for which use of rudder angles to control the vessel is more effective than for steering courses.

Because it is difficult to obtain international standardization of navigation and communications systems, local electronic navigation systems may be needed to extend the benefit of DGPS positioning accuracy to the piloting of all ships in U.S. waters. A PCNS system may be needed for use aboard unequipped vessels that are required to have this capability. The PCNS also might be used as a primary navigational aid in lieu of, or to supplement, ship's equipment. For implementation of such a system as well as installed electronic charting systems

- DGPS coverage will need to be fully operational;
- electronic chart data bases will be needed for waters where portable systems are used;
- chart updating and electronic chart correction capabilities will be needed; and
- the legal status of electronic charts will need to be resolved.

RECOMMENDATION 34: The U.S. Coast Guard and the Maritime Administration should leverage earlier and existing research and should empirically evaluate the impact of advanced electronic positioning systems, automated steering systems, and integrated bridge and ship-control systems (including artificial intelligence and neural networks) on:

- ***the safety of piloting and navigation;***
- ***the practice of piloting, particularly by ship's pilots and bridge watch teams of the future;***
- ***use of traditional aids to navigation; and***
- ***organizational forms and practices that may be required for safe navigation in the future.***

RECOMMENDATION 35: The Maritime Administration and the U.S. Coast Guard should encourage the development and enhancement of integrated navigation systems (including portable and hand-held units). The U.S. Coast Guard, National Oceanic and Atmospheric Administration, and the U.S. Army Corps of Engineers should examine and encourage development of real-time environmental data systems as well as chart-updating and correction systems.

Communications

Effective exchange of information between vessels and with shore-based navigational support units is essential to navigation safety. Voice communica tion is especially important for passing important and perishable information. However, use of voice communication

- is inefficient for passing general navigational information;
- introduces the potential for additional human error in acquiring, screening, and interpreting navigational information;
- can result in information overload of bridge teams and pilots;
- can interfere with onboard actions to resolve "close quarters" and "in extremis" situations; and
- is prone to interference from unauthorized or inappropriate use.

VTS operations use voice radio communications intensively. The amount of information transmitted to a vessel represents a shore-based operator's estimate of that vessel's information needs. Reliance on overheard transmissions and general traffic broadcasts to provide a complete traffic picture leaves the acquisition of information to chance and introduces opportunities for human error. Adverse operating conditions, which increase the use of voice radio, further stress the capability for effective information exchange.

Electronic data links and installed or portable communications systems integrated with electronic charts and DGPS positioning capabilities are feasible; prototypes are being introduced in marine navigation. Although not mature technologies, these systems can potentially be used to provide substantially more data instantaneously to bridge teams and pilots than is now possible; moreover, it will be in a form that permits onboard interpretation. There are no technical or operating standards for marine data transmission systems, and changes to operating practices would necessitate special training in system use (see recommendation 4). The utility of electronic systems for information transfer and interpretation has not been demonstrated in maneuvering situations that require the pilot's constant attention or where bridge team support is minimal.

Improvements are needed in communications to enhance essential voice communications and to provide a more efficient and effective means for disseminating essential operational information.

RECOMMENDATION 36: The U.S. Coast Guard, in coordination with the Maritime Administration, the Federal Communications Commission, National Oceanic and Atmospheric Administration, Army Corps of Engineers, and the Radio Technical Commission for Maritime Services, should assess electronic data links as a primary means for transmitting and receiving information needed for safe and efficient navigation and piloting of commercial vessels. In particular, measures to reduce dependency on voice radio communications in VTS operations should be assessed. The U.S. Coast Guard and Federal Communications Commission should also investigate and assess alleged unauthorized use of bridge-to-bridge voice radio frequencies and take such enforcement action as may be indicated.

MARINE NAVIGATION AND PILOTING RESEARCH NEEDS

The extensive and rapid changes occurring in ship and navigation technologies, manning and operating practices, and the nation's status as a port-state and flag state, have created substantial uncertainties about the performance of virtually all marine transportation systems. The limited research literature that is available focuses primarily on ships and technology. Coast Guard-sponsored research and development programs supporting the application of advanced electronic navigation aids, while not addressing all application issues, are generally keeping pace with the development of these technologies.

Past recommendations to improve safety data have had little effect except to motivate Coast Guard efforts to make its existing marine data bases compatible and to improve data collection on human systems. Available research on human systems and safety performance is often based on data that were not designed to answer questions about human performance. Also, the pioneering work in human systems sponsored by the Maritime Administration and the Coast Guard has become dated, because of the absence of dedicated, continuing research to identify trends and assess their effects and implications. These problems have coincided with the privatization of operations at the Maritime Administration's Computer Aided Operations Research Facility, a change in the facility's focus from fundamental to applied research and training, the closing of the National Maritime Research Center, and severe reductions in the Maritime Administration's research funds. Organizational research pertaining to marine transportation is virtually nonexistent. The Coast Guard's establishment of a human systems research staff is an important step in addressing the human dimension in marine accidents.

Marine safety and economic efficiency would benefit from the program of dedicated fundamental research identified in Chapter 8. Research needs are substantial and cross the missions of the Coast Guard, Maritime Administration, National Oceanic and Atmospheric Administration, Army Corps of Engineers, and the National Transportation Safety Board. Therefore, a comprehensive cooperative research program is indicated. The Department of Transportation is an appropriate choice to coordinate the cooperative research program in marine transportation.

RECOMMENDATION 37: The Department of Transportation, in consultation with the Department of Commerce and the Department of the Army, should establish a comprehensive, cooperative research program focusing on navigation safety and piloting. The program should be led by a Department of Transportation agency designated by the Secretary of Transportation and should include participation by the U.S. Coast Guard, Maritime Administration, National Oceanic and Atmospheric Administration, U.S. Army Corps of Engineers, and National Transportation Safety Board. The

program should be designed to address the existing, substantial research needs in marine-systems safety, waterways management, navigation and piloting technology, port-state versus flag-state policy, navigation and piloting practices, and human systems. Research sponsored by the Department of Defense, especially the U.S. Navy, should be examined for relevance; insofar as practical, lessons from this research should be leveraged into the Department of Transportation cooperative research program. Research needs should be prioritized in each area according to their prospective contribution to marine safety and economic efficiency. Congress should authorize the research program and appropriate funding for its execution.

Appendixes

Appendix A

Biographies

ALBERT J. HERBERGER, Chair (until September 14, 1993), is Maritime Administrator, U.S. Maritime Administration. During the Study, he was Vice President, Maritime Affairs, with the International Planning and Analysis Center. He specializes in military sealift and naval surface warfare. His executive management experience includes manpower, training, logistics, and marine transportation. Vice Admiral Herberger completed U.S. Navy service as Deputy Commander, U.S. Transportation Command, where he was responsible for developing and implementing a strategy to promote government and civil sector support for improvements for all modes of national transportation. This included development of a transportation network designed to incorporate both civil-sector and government programs for traffic management and computer-based information systems. He also served as Director for Logistics, U.S. Atlantic Fleet, where he was responsible for logistics planning and maintenance management of over 300 ships, as well as aircraft squadrons and shoreside facilities. His 18 years operational service in the Navy and the merchant marine included deck officer and naval command experience in ships and destroyer groups. Vice Admiral Herberger received his B.S. from the U.S. Merchant Marine Academy and completed the engineering science curriculum at the U.S. Naval Postgraduate School.

MARTHA GRABOWSKI, Chair (from September 17, 1993), is the Joseph Georg Professor at LeMoyne College, Syracuse, New York; Research Assistant Professor in the Department of Decision Sciences and Engineering Systems at Rensselaer Polytechnic Institute; and member of the Marine Board, National Research Council. Dr. Grabowski previously served as Program Integration Man ager with General Electric's corporate research and development center. She has been investigating the effects of smaller shipboard crews and advanced technology on maritime safety, methods for streamlined development of information systems, and the organizational impact of information systems. She developed a piloting expert system for use with integrated bridge systems for the Maritime Administration. Dr. Grabowski served as a licensed deck officer in the U.S. merchant marine and is a Lieutenant Commander in the U.S. Naval Reserve. Her afloat experience includes deck officer assignment aboard liquefied natural gas carriers, tankers, and integrated tug-and-barges. Dr. Grabowski received her B.S. in marine transportation from the U.S. Merchant Marine Academy and earned her M.S in industrial engineering, M.B.A., and Ph.D. in information systems/artificial intelligence from Rensselaer Polytechnic Institute.

BERNHARD J. ABRAHAMSSON is Professor of Economics and Chairman of the Division of Business and Economics, University of Wisconsin—Superior. Dr. Abrahamsson specializes in international economics with emphasis on trade; economics and policy of ocean, shipping and energy; and transportation. He has held positions at six universities, the Woods Hole Oceanographic Institution, the International Monetary Fund, and recently was Head of the Department of Marine Transportation at the U.S. Merchant Marine Academy. His consultancies have included the World Bank, the National Advisory Committee on Oceans and Atmosphere, Federal Maritime Commission, General Accounting Office, and the RAND Corporation. He served on the National Research Council's Ocean Policy Committee (1975–78) and that committee's Marine Technical Assistance Group (1978–82). Dr. Abrahamsson graduated from the Stockholm Merchant Marine Academy, received his unlimited Master Mariner's license from the Swedish Board of Trade, he received a Reserve Officer's Commission from the Royal Swedish Naval College, and served aboard merchant ships for 15 years. His publications include eight books as author, coauthor, or contributor and numerous professional articles and major papers. He has lectured extensively, delivering conference papers worldwide to industrial, academic, and government audiences. Dr. Abrahamsson received his B.B.A. degree in international trade from the City College of New York and earned his M.S. and Ph.D. in economics from the University of Wisconsin—Madison.

JAMES E. BAKER is a consultant in port operations and instructor at the Texas A&M University at Galveston. During the study, Captain Baker was Director of Operations, Port of Houston, where he was responsible for daily operation of the port's cargo handling and container facilities. He is a special advisor to the U.S. Coast Guard's Vessel Traffic Service 2000 project. He completed service with Lykes Lines as Assistant Vice President. In addition to service as Port Captain and Manager, Marine Division West Gulf, Captain Baker also sailed as Chief Officer with Lykes Lines and holds an unlimited Masters license and endorsement as Federal First Class Pilot, Houston Ship Channel. He has been Chairman of the Department of Transportation's Houston-Galveston Navigation Safety Advisory Committee from 1982. He was a member of the Advisory Committee for Formation of Operation Guidelines of Houston/Galveston Vessel Traffic Service and chaired the Captains Technical Committee of the West Gulf Maritime Association from 1972–1986. Captain Baker received his B.S. from the U.S. Merchant Marine Academy.

RONALD BRAFF is a Principal Engineer at The MITRE Corporation's Center for Advanced Aviation System Development. He is the editor of *Navigation: Journal of the Institute of Navigation*, and consulting editor in navigation for the *McGraw-Hill Encyclopedia of Science and Technology.* At MITRE since 1970, Mr. Braff has been involved in many aspects of air navigation technology. He is test director for the Federal Aviation Administration's large-scale program to determine the feasibility of using the Differential Global Positioning System (DGPS) for Category III precision approaches, and provides technical oversight of MITRE's navigation research for the Federal Aviation Administration. Previous work at MITRE included supervision of technical support for Federal Aviation Administration navigation policy decisions with emphasis on air navigation's stringent requirements for integrity, availability, and continuity of service. He identified GPS integrity problems, and originated the idea for the satellite-broadcast GPS integrity channel, which is currently in the Federal Aviation Administration implementation process. Mr. Braff is also experienced as a technical manager and engineer in the development and evaluation of advance concepts for air traffic control surveillance, communications, and automation functions. He was previously with Computer Sciences Corporation where he was involved in the design of a military tactical air traffic management system, and the Federal Aviation Administration Technical Center, where he conducted experimental and theoretical evaluation of advance navigation systems. Mr. Braff is a member of the Institute of Electrical and Electronic Engineers and a member of the Council of the Institute of Navigation. He received his B.S. in physics from Montana State University and M.S.E.E. from New York University.

ROBERT M. FREEMAN is Technology Development Coordinator, SeaRiver Maritime (formerly Exxon Shipping Company). He previously held economics, planning, and environmental conservation positions with Exxon, and he served in the U.S. Navy for 9 years. His experience with Exxon included building, conversion, and engineering/technical programs and involved work as project manager for the construction of two very large tankers. These programs included retrofit of distributed control systems on five tankships, which resulted in the first certifications for unattended engine rooms on U.S.-flag steam vessels. Since 1984, Mr. Freeman has been involved with development of integrated bridge systems for operational control of tankships. He was responsible for de velopment of an automated integrated bridge system that was installed on a very large Exxon tankship for at sea testing and development as a prototype for fleet installation. He completed service in the U.S. Naval Reserve as Commander. Mr. Freeman received his B.S. in mechanical engineering and M.B.A. in finance from the University of Pittsburgh.

JEAN GRAFF has managed the SOGREAH Port Revel Marine Research and Shiphandling Training Centre, France, since 1981. He has been project leader for a number of scale-model studies of ship and towboat maneuvering characteristics in simulated harbors and waterways. He previously served as engineer responsible for Europe and the Middle East in SOGREAH's Department of External Relations. He was engineer in SOGREAH's Hydrology and Hydrography Sections, where he was responsible for in situ measurements to obtain the data required for port and coastal studies carried out by the Maritime Engineering Section. Before joining SOGREAH, Mr. Graff attended the French Navy's training school for reserve officers and served as officer of the deck aboard French naval vessels. He also was Mate with the Compagnie Generale Maritime, serving as deck officer aboard various ships. Mr. Graff received his diploma from the National Merchant Navy School in France in 1961 and received his Oceangoing Mate's license in 1963.

PAUL LANE IVES, JR., is a state (Pennsylvania) and federally-licensed marine pilot and a member of the Pilots' Association for the Bay and River Delaware. During the study, Captain Ives was President of the Association and Secretary-Treasurer of the American Pilots Association. He also holds a Coast Guard license as Master of Steam and Motor Vessels upon Bays, Sounds and Lakes. His Federal Communications Commission licenses are Radiotelephone Operator First Class with Ship Radar endorsement and Amateur Radio Operator. He previously held a private pilot's license for light aircraft. Captain Ives' long involvement with technological improvement of methods of pilotage includes the application of bridge-to-bridge radio communications, vessel traffic services, and computer-based real-time tide and current information for the Delaware Bay and River. Captain Ives is a member of the Board of Directors of the Radio Technical Commission for Marine Services and chaired the Joint Executive Committee for the Improvement and Development of the Philadelphia Port Area. He received his B.A. in history and political science from the John Hopkins University.

WALTER PARKER is President, Parker Associates. He specializes in transportation, telecommunications, and regional planning and is experienced in both aviation and marine systems, as well as marine pilotage laws and customs. Mr. Parker was an evaluator for educational broadcasting use of satellite systems, planned a long-distance education network for Alaska, and provided the state with its first long-range telecommunications program. He wrote the environmental and technical stipulations for the proposed Northern Tier Pipeline for Washington State and proposed stipulations for the Northwest Gas Pipeline for the state of Alaska. Be also was environmental consultant and technical staff director on the Aleyska Pipeline for the State of Alaska Pipeline Office. Prior to that, he completed a long career with the Federal Aviation Administration as Transportation Planning Officer. Mr. Parker's Federal Aviation Administration work included service as an air traffic controller, regional evaluation, regional planning, and systems requirements. He was Chairman of the Alaska Oil Spill Commission, Oil Tanker Task Force, and Alaska Telecommunications Work Group. He was U.S. Delegate to the 1976 United National Conference on Habitat. Mr. Parker is President of the Alaska Academy of Engineering and Sciences. He received his B.A. (History and Anthropology) from the University of Alaska, Fairbanks. He graduated from the Administrative Management Development Program, with majors in political science and public administration, at Syracuse University. Mr. Parker also completed graduate studies in economics at the University of Puget Sound, Tacoma, and in Soviet maritime and fisheries policy at the Sino-Soviet Institute, The George Washington University.

KARLENE H. ROBERTS is a Professor in the School of Business Administration, University of California at Berkeley. She is also Research Psychologist with the Institute of Industrial Relations. Dr. Roberts teaches an M.B.A.-level course on the design and management of complex systems that have potential to cause catastrophic damage to themselves and their environments. Her research has focused on human-factors aspects of high-reliability-enhancing organizations as they pertain to the U.S. Navy's nuclear powered aircraft carriers, the Federal Aviation Administration's air traffic control system, Pacific Gas and Electric Company's nuclear plant at Diablo Canyon, and human systems in commercial marine operations. She has also assisting in doctoral research into management aspects of oil rig operations. She has published extensively on organizational behavior in hazardous operations, communications, and human performance. Dr. Roberts is a Fellow of the American Psychological Association and the Academy of Management. She received her B.A. from Stanford University and earned her Ph.D. in Psychology from the University of California, Berkeley.

WILLIAM J. SCHRENK has been an attorney with the Natural Resources Defense Council since 1988. There, his work has focused on maritime activities, and includes legal analysis of pilotage laws. A member, Bar of the State of New York and Association of the Bar of the City of New York, Mr. Schrenk retired as a partner in the law firm of Lawyer, Cravath, Swaine and Moore in 1987. He was resident partner in Paris (1963–64) and London (1977–79). His practice was primarily in financial and corporate matters. Prior to entering private legal prac tice, Mr. Schrenk was Executive Secretary, Study Committee for the European Movement, Cambridge, Massachusetts (1952–53); lawyer with the U.S. High Commission for Germany, Frankfurt and Bonn (1950–52); and lawyer with the Economic Cooperation Administration in Washington, D.C. (1949–50). He served as a naval officer from 1943–46 in the Pacific Theater. Mr. Schrenk received his B.S. from Case Institute of Technology and earned his J.D. from the University of Michigan Law School.

FRANK SEITZ is a principal in and consultant with SimShip Corporation where he specializes in marine simulation training. He previously was a marine consultant with Marine Safety International, where he served as Senior Marine Advisor and Project Manager at the Computer Aided Operations Research Facility at Kings Point, New York, prior to forming SimShip. Captain Seitz holds a Coast Guard Unlimited Masters license and endorsements as Federal First Class Pilot for New York Harbor, Lower and Upper Bay, Bahia de San Juan, Puerto Rico, Prince William Sound, and Port Valdez, Alaska. He also holds a commercial aviation pilot's license. Captain Seitz has extensive experience as captain of dry cargo, tanker, container, chemical carrier, and special purpose ships; navigator experience aboard the passenger ship *America*; and was the original master of the very large crude carrier *SS B.T. San Diego* operating in the Trans-Alaska Pipeline Service. He was recalled to active service in 1987 to bring the first reflagged Kuwaiti tanker, ultra large crude carrier *Bridgeton*, into the Persian Gulf. Upon return from the Gulf, he designed and implemented an indoctrination course and manual for future U.S. masters of reflagged ships, and headed an advisory team, which conducted debriefings and advisory sessions before the National Security Council and Maritime Administrator. Captain Seitz previously was ship master for the Puget Sound tanker trials. He has served as chief instructor for advanced shiphandling and readiness courses at the Computer Aided Operations Research Facility; the Maritime Training and Research Center in Toledo, Ohio; and the Marine Safety International Training Complex in Newport, Rhode Island. Captain Seitz has headed simulation research projects supporting harbor design, ships operations, and human factors, and participated in the Panama Canal Widening Study. He has published numerous articles and papers on topics including shipboard management, bridge team training, master-pilot relationships, bridge design, ship handling, and vessel-performance monitoring. Captain Seitz received his B.S. from the U.S. Merchant Marine Academy.

EUGENE F. SWEENEY is Senior Vice President with Hvide Shipping, where he also served as Vice President-Operations, with responsibilities for deep-sea and vessel operations, including all maintenance and repair activities, personnel, training and safety functions, and vessel management. Mr. Sweeney holds a Coast Guard Unlimited Master license and has eighteen years of Naval Re serve officer experience. Prior to joining Hvide Shipping, he completed a 17-year career with Texaco as Manager of Operations for the Texaco U.S. fleet. He also served as Superintendent of Safety and Training for Texaco's four international fleets and was Marine Superintendent for New England operations. He was president of the Chemical Carriers Association. Mr. Sweeney received his B.S. from the State University of New York Maritime College and his M.S. in marine transportation from the State University of New York.

ARTHUR J. THOMAS is a state (California) and federally-licensed marine pilot; member of the San Francisco Bar Pilots Association; Vice President, Pacific Coast States, American Pilots Association; and West Coast Regional Vice President, International Association of Masters, Mates and Pilots. During the study, he was president of the San Francisco Bar Pilots Association. Captain Thomas holds Coast Guard licenses as Master, Oceans, Unlimited and First Class Pilot for San Francisco Bar, bays, and tributaries and a corresponding California Pilot license. He has sailed in all licensed deck officer positions including Master. He also holds a Federal Aviation Administration license as Commercial Aircraft Pilot, multi-engine, land and sea, instrument rated. He is a member of the International Maritime Pilots Association International Technical Committee to the International Maritime Organization; Chairman, Harbor Safety Committee, San Francisco Bay Region, California Department of Fish and Game, Office of Oil Spill Prevention and Response; and Chairman of the San Francisco State Pilot Commission's pilot training and evaluation committee. Earlier, Captain Thomas served as chairman of the Department of Transportation Harbor Safety Advisory Committee for the San Francisco area and was a member of the Department of Transportation's Rules of the Road Advisory Committee, where he chaired the Pilot Rules and Radiotelephone Working Groups. Previously, he served as marine superintendent and port captain for States Steamship Company and served as both master and chief officer on cargo ships. He served as chief officer aboard vessels operated by the Military Sea Transportation Service and Kaiser Gypsum Carriers and as deck officer aboard American President Lines vessels. Captain Thomas completed U.S. Naval Reserve service as Captain. He received his B.S. in Nautical Science and Astronomy from the California Maritime Academy.

Appendix B

Acknowledgments

The Committee on Advances in Navigation and Piloting owes a debt of gratitude to the many individuals and organizations that contributed to this assessment. It was an undertaking that far exceeded the committee's expectations in terms of its complexity.

The committee acknowledges and expresses its gratitude for the special technical support provided by many members of the marine community. In particular: Thomas Allegretti, The American Waterways Operators, coordinated and moderated towing industry presentations to the committee at its Houston meeting, and he coordinated preparation of a technical paper for the committee on pilotage in the towing industry; Scott Bartlett and Richard Kenney, Sperry Marine, hosted a demonstration and provided technical information on integrated bridge systems (IBS) and vessel traffic services (VTS) technology; Joseph Cox, American Institute of Merchant Shipping, coordinated and moderated shipping-industry presentations to the committee at its Houston meeting; Edward T. Gates, Arceneaux and Gates, provided insight on hydrodynamic forces acting on ships; John Hartke, U.S. Coast Guard Headquarters, provided technical advice on federal pilotage; Paul Kirchner, American Pilots' Association, provided technical support concerning state pilotage laws and regulations; John MacLeod, Canadian Coast Guard Traffic Centre Vancouver, provided background support for the VTS assessment and hosted a visit to his facility; Donald Jarrell, Canadian Coast Guard Traffic Centre Vancouver, provided technical insight on the similarities and differences between air traffic control and marine traffic regulation in the Port of Vancouver, British Columbia; and Warren Schneeweis, U.S. Coast Guard Vessel Traffic Service New York, and Spencer Martin, Canadian Coast Guard, Ottawa, provided technical support for the committee's background assessment of VTS. Essential encouragement and technical support was also provided by Pat J. Neely, American Pilot's Association; George Quick, International Organization of Masters, Mates, and Pilots; and William A. Arata, Biscayne Bay Pilots.

The assistance that was provided in arranging meetings, testimony, site visits, and observation trips, and in preparing descriptions of pilotage routes, practices, administration, and professional development programs, was invaluable to the completion of the committee's work. The committee wishes to especially acknowledge those who, in addition to corresponding with the committee, met with members and staff during meetings and site visits to provide the range of perspectives and technical detail that was necessary to the preparation of a comprehensive report.

During the course of the study, a delegation of committee members visited selected locations in Europe. The committee is especially indebted to W. Ph. van Maanen, formerly with the Rotterdam Port Authority, who assisted in organizing and moderating substantial presentations and discussions of marine navigation and piloting issues in the Netherlands, and who provided reference materials on the use of marine simulation for waterways design and professional development. Marianne Roelofs, Rotterdam Port Authority, assisted with arrangements for the delegation's meetings in Rotterdam.

Special thanks are also extended to the many participants who made the Rotterdam meetings a success, including S. N. Zuurbier, Bernt R. Koning, and Jan Kloos, Reg. Loodsencorporatie Rotterdam-Rijnmond, who provided detailed insight on pilotage in the Netherlands and arranged and coordinated a visit to the Rotterdam Pilot's North Sea station boats; Robert Hofstee, Rotterdam Pilots, who provided advice and arranged for a committee member to observe the piloting of a very large crude carrier into the Maas River; J. Hussem, who hosted the delegation's visit to the Flushing VTS, Scheldt Coordination Centre, and arranged and moderated presentations on marine traffic regulation and crisis management involving both Belgian and Dutch authorities; James Lindahl, SILJA Line Ferries, who graciously arranged for members of the delegation to observe the operation of IBS on the Stockholm-Turku and Stockholm-Helsinki routes; Olle Noord, master, Motor Ship Silja Symphony, who provided detailed advice on the use of IBS; I. M. H. Slater, Thames Navigation Service, who briefed members of the delegation on VTS operations, hosted a visit to the London VTS, and provided technical advice; James Whitton, Thames Navigation Service, who briefed the committee on changes in pilotage in the United Kingdom and hosted a visit to the Port of London Authority pilot station; Benny Pettersson, who provided insight on constant radius turns and use of IBS in piloting; Bo Lilljegren, Sven G. Gyldén, and Hans O. G. Hederström, who provided insight on pilotage in Sweden and hosted a visit to the Gothenburg pilot station and VTS; Captain Beitikainen, Finnish Pilots Association, Martti Heikkila, Technical Research Center of Finland, and Dieter Muntzel, Helsinki Port Authority, who provided insight on pilotage and marine traffic regulation in Finland; and the staff of the SOGREAH Port Revel Marine Research and Shiphandling Training Centre, which provided expert insight on the combined use of lectures, manned ship models, and debriefs.

Expert testimony was provided by many members of the marine community and other interested individuals and organizations during meetings, field trips, and site visits. The special contributions of the following individuals and organizations are acknowledged: Anthony C. Alejandro, U.S. Coast Guard Captain of the Port, Houston; Richard Beadon, formerly with the U.S. Merchant Marine Academy and now with Seamen's Church Institute, New York; Richard Beard, State of Washington; Lou Bettinelli, Interport Pilots Agency; Gary Bird, U.S. Coast Guard, Eighth District: Leo Black, U.S. Coast Guard Headquarters; Vincent Black, Sandy Hook Pilots; William Bock, Puget Sound Pilots, Robert Bohlman, Norton Lilly International; Fred Boyd, Associated Federal Coast Pilots of Louisiana; Leo Brien, Pacific Merchant Shipping Association; Dave Buchanan, Maritrans; Dominic Casano, Hudson River Pilots; C. E. Clayton, New Orleans-Baton Rouge Steamship Pilots Association; Scott Cooper, USCG MSO New Orleans; Harry Crooks, Maritime Training Research Center; Kevin Q. Davis, Stoel, Rives, Boly, Jones & Grey; Mickey D. DeHart, Gulf Coast Transit Company; Mark Delesdernier, Jr., Crescent River Port Pilots Association; Michael R. Delesdernier, Attorney at Law; Michael Dillon, Columbia River Bar Pilots; George Duffy, Navios Ships Agencies; William G. Duncan, Exxon Shipping Company; Gerrard Dundon, McCormick Pilots; Miklos Endrody, Puget Sound Pilots; Charles H. Erikson, Unical Corporation; Timothy Ferrie, Sandy Hook Pilots; John Fidaleo, U.S. Coast Guard, Eighth District; M. Flavel, Grays Harbor Pilots; Allen A. Flotre, British Columbia Coast Pilots; Victor Fry, Pacific Pilotage Authority; Richard Goodin, Staten Island Ferries; Earl Goodwin, Houston Pilots Association; Martin W. Gould, New Orleans-Baton rouge Steamship Pilot Examiners; Thomas C. Greene, U.S. Coast Guard Captain of the Port, Galveston; F. Eugene Guest, Marine Safety International; Denny Haise, U.S. Coast Guard Marine Safety Office Mobile; Albert Hartberger, U.S. Coast Guard Headquarters; Channing F. Hayden, Jr., New Orleans Steamship Association; Jay Hess, U.S. Coast Guard Marine Inspection Office New York; John Hoopaugh, Hollywood Marine; Michael Hunt, U.S. Coast Guard, VTS Houston-Galveston; Glen Hurn, Columbia River Pilots; Frank Johannessen, New Jersey Board of Commissioners of Pilotage; Russ Johnson, Crowley Maritime; W. R. Kern, Galveston-Texas City Pilots Association; Duane Lange, Maritime Heritage Cruise Lines; Richard Larrabee, U.S. Coast Guard Captain of the Port, New York; Eric Larrsen, Seamen's Church Institute; Edward Larson, Houston Pilots Association; W. Bruce Law, Allied Towing; Jack Levine, Associated Branch Pilots; Darlene Maddenwald, Washington Environmental Council; Gary Maddox, Tampa Bay Pilots; Richard E. Manchester, Lykes Brothers Steamship Company; Edmond Mandin, American President Lines (retired); William Marshall,

Puget Sound Steamship Association; Thomas McKey, Bogle & Gates; Jacques Michell, marine pilot/consultant; Floyd Miller, New York Maritime Academy; Robert Moore, New York/New Jersey Docking Masters; Henry W. Motekaitis, Puget Sound Vessel Traffic Service; Roger Mowery, U.S. Coast Guard Marine Safety Office, Seattle; Mark Nichols, Lewis and Clark Pilots; Robert Nichols, Office of the Governor, state of Washington; Glenn Paine, Maritime Institute of Technology; William Peterson, Sandy Hook Pilots; Rex Pollitt, Oregon Board of Marine Pilots; Robert Pouch, Board of Commissioners of Pilots of the State of New York; James Radice, U.S. Coast Guard Headquarters; Terry Rice, Thirteenth Coast Guard District; Arthur Roche, Sandy Hook Pilots; James H. Sanborn, Maritrans; George Sandberg, U.S. Merchant Marine Academy; Steve Scalzo, Foss Maritime; Fred Schilling, U.S. Army Corps of Engineers, New Orleans District; William Schubert, U.S. Maritime Administration, Houston; K. I. Selindis, Sabine Pilots Association; Chip Sharp, Puget Sound Vessel Traffic Service; Burt Shearer, Washington State Board of Pilot Commissioners; Jack Smith, Galveston Pilots Association; J. Michael Solossi, U.S. Coast Guard Headquarters; Richard Stewart, U.S. Merchant Marine Academy; Christopher Stone, U.S. Coast Guard Headquarters; Larry Strain, American Commercial Barge Line; John Strong, Jacobsens Pilot Service; Jim Sweet, Puget Sound Pilots; Ted Thorjussen, West Gulf Maritime Association; William Tuttle, Metropolitan Pilots; Jack Vonfeld, Columbia River Pilots; Thomas Walsh, Sandy Hook Pilots; David Wells, Island Tug & Barge Company; Wayne Whyte, British Columbia Coast Pilots; Fred Wilkerson, Texas State Pilot Association; and John Williams, Aransas-Corpus Christi Pilots Association. The committee also expresses its gratitude to the many other individuals who supported this assessment.

Appendix C

Papers Prepared for This Study

(Reference Dates are Keyed to the Bibliography)

Atkinson, J. A. 1991. Unfilled Needs Relating to Ship Control and Suggestions for how to Fill Them through the Use of Modern Technology. Unpublished paper prepared for the Committee on Advances in Navigation and Piloting, Marine Board, National Research Council, Washington, D.C.

AWO. 1992b. Report to the Marine Board Committee on Advances in Navigation and Piloting on Pilotage in the Coastal Towing Industry. Unpublished paper prepared for the Committee on Advances in Navigation, Marine Board, National Research Council, by The American Waterways Operators, Alexandria, Virginia.

Braff, R., W. Young, P. L. Ives, Jr., F. Seitz, and W. Parker. 1993. Applying National Airspace Features in the Marine Operating Environment. Unpublished working paper prepared for the Committee on Advances in Navigation and Piloting, Marine Board, National Research Council, Washington, D.C.

Freeman, R. M. 1993. Background Paper: Quantitative Risk Assessment. Unpublished working paper prepared for the Committee on Advances in Navigation and Piloting, Marine Board, National Research Council, Washington, D.C.

Graff, J. 1993. Physical Forces Acting on a Ship. Unpublished working paper prepared for the Committee on Advances in Navigation and Piloting, Marine Board, National Research Council, Washington, D.C.

Herberger, A. J., J. Graff, P. L. Ives, Jr., K. Roberts, and W. Young. 1991. Committee on Advances in Navigation and Piloting: Trip Report of the European Delegation. Unpublished working paper prepared for the Committee on Advances in Navigation and Piloting, Marine Board, National Research Council, Washington, D.C.

Ives, P. L., Jr., W. Parker, F. Seitz, and W. Young. 1992. Background Paper: Assessment of Vessel Traffic Services. Unpublished working paper prepared for the Committee on Advances in Navigation and Piloting, Marine Board, National Research Council, Washington, D.C.

Ramaswamy, S. 1991. Literature Review on Navigation and Piloting. Unpublished contract report to the Marine Board, National Research Council, Washington, D.C.

Ramaswamy, S., and M. Grabowski. 1992. Summary of Responses to the Committee on Advances in Navigation and Piloting's Letter of Inquiry. Unpublished report to the Marine Board, National Research Council, Washington, D.C.

Thomas, A. J. 1993. Background Paper: Unification of Federal and State Licensed Pilots, San Francisco Bay Region. Unpublished working paper prepared for the Committee on Advances in Navigation and Piloting, Marine Board, National Research Council, Washington, D.C.

Young, W. 1993. Backround Paper: Safety Issues. Unpublished working paper prepared for the Committee on Advances in Navigation and Piloting, Marine Board, National Research Council, Washington, D.C.

Appendix D

A Review of Pilotage Studies Covering U.S. Navigable Waters

Numerous navigation and piloting studies, analyses, and investigations have been undertaken in the past 50 years. Several of these studies addressed safety issues, state and federal piloting-safety records, pilot governance, and piloting practice, as well as developed empirical piloting-safety measures. A review of these piloting and navigation references is presented in this appendix (Box D-1). These studies were reviewed and considered by the committee. In some cases, the studies formed the historical context within which the committee conducted its work; in other cases, the studies represented current and recent past assessments that addressed issues of import to the committee.

The reports reviewed have been grouped by general topic headings, although many topics and reports overlap. The topic groupings in this appendix include state and federal pilot issues, port-level safety analyses, pilot governance and administration, vessel safety, piloting practice, and analyses of marine accidents and incidents. Many of the studies are limited by their reliance on the data available to support these investigations—primarily from the Coast Guard's automated main casualty (CASMAIN) data base. As has been noted before, these data are incomplete and inadequate for assessing the safety of navigation and piloting. (Research needs with respect to safety data are discussed in Chapter 8.)

State And Federal Pilot Issues

Comparisons of state and federal pilotage have been conducted for a number of years. For instance, in 1942, the U.S. Coast Guard, at the request of the Navy Department, conducted an analysis of pilotage in the United States that included

BOX D-1 LITERATURE REVIEWED

A Report of Pilotage in the United States (USCG, 1942).

Great Lakes Pilotage Review (DOT, 1972).

Special Study of Collisions within the Navigable Waters of the United States: Consideration of Alternative Preventive Measures (NTSB, 1972).

Investigation of Human Factors in Marine Casualties (Bryant et al., 1987).

Summary of Analysis of Oceangoing Tank Barge Navigation Incidents in Inland Waters (TBS, 1985).

Great Lakes Pilotage Study (DOT, 1988).

Marine Accident Report, Collision between the Hong Kong Flag Bulk Carrier *Petersfield* and the U.S. towboat *Bayou Boeuf* and tow New Orleans, Louisiana (NTSB, 1988a).

A Comparative Assessment of State Pilot Safety (Leis, 1989).

Report of the Pilotage Study Group (USCG, 1989).

Report of the Tanker Study Group (Bell et al., 1989).

Final Report on the Audit of the U.S. Coast Guard's Oversight and Management of the Great Lakes Pilotage Program (DOT, 1990).

Marine Accident Report, Grounding of the US Tankship *Exxon Valdez* on Bligh Reef, Prince William Sound, near Valdez, Alaska (NTSB, 1990).

Report of a Board of Inquiry Convened to Investigate a Series of Recent Incidents involving Commercial Vessels in the Kill van Kull/Arthur Kill area of the Port of New York/New Jersey (USCG, 1990a).

Response to the Board of Inquiry Convened to Investigate a Series of Recent Incidents involving Commercial Vessels in the Kill Van Kull/Arthur Kill area of the Port of New York/New Jersey (Kime, 1990).

A Comparative Safety Assessment of State and Federal Pilots (Booz, Allen and Hamilton, 1991).

Management of Safety (Nautical Institute 1991b).

Marine Accident Report, Grounding of the Greek Tankship *World Prodigy* off the Coast of Rhode Island (NTSB, 1991b).

Our Way (Wallenius Lines, 1991).

Port Needs Study (Maio et al., 1991).

The Human Element in Shipping Casualties (Bryant, 1991).

A Critique of Two State Pilot Safety Studies (Leis, 1992).

Report to the Marine Board Committee on Advances in Navigation and Piloting (AWO, 1992b).

Safer Navigation in the '90's: Integrated Bridge Systems (Hederström and Gyldén, 1992).

Performance Audit of the Regulation of Marine Piloting, Report No. 11914 (State of Florida, 1992).

A Comparison of Marine Casualties Involving Pilots Operating Under the Authority of a Federal License and Pilots Operating under the Authority of a State License (USCG, 1993c).

a comparison of state and federal pilots and piloting practices (USCG, 1942). The Committee on Advances in Navigation and Piloting reviewed a number of studies addressing federal and state pilot issues: the 1942 Coast Guard study, three different approaches to weighing state versus federal pilotage (Booz, Allen and Hamilton, 1991; Leis, 1989); and a rebuttal to the Booz, Allen and Hamilton report, Leis (1992); a National Transportation Safety Board report (NTSB, 1988a), and a Coast Guard rebuttal to that 1988 report (USCG, 1993c).

1942 Coast Guard Study

The 1942 Coast Guard study delineated the following assets and liabilities of the state and federal pilotage systems:

Assets of the State Pilot Systems

- *It has withstood the test of time*. Since 1912, no attempt has been made to wrest control of pilotage of registered vessels away from the states (Ashe, 1984; Parks, 1988), and the 1942 attempt, as well as previous attempts, failed because it could not be demonstrated that such changes were either necessary or beneficial to commercial interests.
- *State pilotage has been maintained at a generally high standard*. The long record of state pilot associations, taken as a group, is better than good. The state-licensed pilots, as a class, are responsible, proud of their work, and probably at least as capable as the pilots of any other country.

Weaknesses of the State Pilot System

- *Lack of uniformity*. Variation in the administration and operation of pilot groups was cited as a weakness of the state pilotage system, particularly "in a war, where its outcome depends on the safe and speedy movement of shipping."
- *Rotary system*. The practice of designating a pilot for a particularly difficult job because it is his turn, rather than because he is the best qualified pilot available, was in use in 1942, as it is today.
- *Compulsory physical exams and compulsory retirement as not common.* The fact that very few states mandated periodic physical examinations for pilots, and that very few pilot associations set a mandatory retirement age, was considered to be a weakness.
- *Weak leadership in some ports*. Lack of internal discipline was cited as a weakness; in some ports, "men are unable to maintain efficient organizations."
- *Failure of some states to make pilotage compulsory in certain dangerous waters*. The fact that the federal government had left it to the states to designate waters for which pilotage was compulsory for registered vessels was an issue cited in the report.

Weaknesses of the Federal Pilot System

- Pilot licenses, or piloting endorsements on officers' licenses, are renewed every 5 years, regardless of the length of time the applicant has been away from the pilotage waters in question.
- Physical examinations are required only at 5-year intervals, and there is no upper age limit. This weakness was also identified as a weakness of the state pilotage system.
- Suspension of a pilot grievously at fault is not immediate.
- Federal control over state-licensed pilots is by agreement only and is not complete. The report stated that in 1937, all 32 state pilot groups of the American Pilot's Association were parties to a written agreement to voluntarily submit to federal investigation and disciplinary action, even though pilots were acting under the authority of state rather than federal licenses. The report said, however, that it was doubtful whether federal action against a pilot acting under his state license could be legally sustained.

Many of the issues identified and considered by the committee with respect to state and federal pilotage issues have not changed substantially in the past 50 years. The 1942 piloting study provides a useful background context for the committee's work, as it places the issues, and discussions about them that have occurred over the years, in a historical perspective.

1989 Battelle/American Pilots' Association Study

In this analysis, performed by Battelle's Columbus Division for the American Pilot's Association (APA), Leis (1989) sought to develop a relationship between the safety performance of state pilots and non-state pilots, both performing pilotage in port areas. State pilots were those designated in Coast Guard casualty data as holding a state license, or both a state license and a federal license; non-state pilots were those performing similar pilotage functions, but "not qualified" for a state license. The report examined *comparative performance* as represented by pilot-caused accidents for each pilot group during the conduct of equivalent pilotage tasks. CASMAIN records were used as the basis of this study.

Methodology

Because data were not available for direct measurement of relative safety performance, the report developed a surrogate measure that would permit the comparative accident rate to be inferred; this "key factor" was computed as accidents occurring per ton of cargo transported. In this measure, accidents were defined as those involving vessel motion (i.e., dynamic accidents), and tons were defined as the tons handled in port areas as derived from the U.S. Army Corps of

Engineers Waterborne Commerce data. Key factors were evaluated for different port areas for each pilot group, and the ratio of these key factors, or the "key factor ratio," was used to infer relative safety performance. That is, the ratio of non-state pilot key factors to state pilot key factors was used as an indicator of relative safety performance.

Key factor ratios were computed for (1) coastal port areas of the contiguous United States, viewed as a single port area; (2) 10 high-activity ports, viewed as a single port area; and (3) eight ports (New York, Baltimore, Philadelphia, Hampton Roads, Tampa, New Orleans/Baton Rouge, Galveston/Houston/Texas City, and Mobile), each viewed as a single port area. (No West Coast ports were included in the third category.) Assumptions made in the report that tended to favor the state pilots were reported to have been adjusted so as to favor the non-state pilot group; thus, the report was characterized as examining a "worst case" scenario for state pilots.

The methodology classified pilots by licensing authority, rather than by function performed (that is, docking evolutions and bar, river, and harbor pilotage). Professional qualifications, risk exposure, performance of ship systems, and performance of navigation technology were not assessed. Safety performance in different operating environments was not normalized to accommodate variations in exposure to risk. Data screening relied heavily on tonnages as the predominant comparison measure.

Findings

Based on the key factor analysis, the report found that non-state pilot groups had experienced 10 to 20 times the number of pilot-caused accidents as had state pilots. Because of the definition of key factor ratios, this result suggested that, for equivalent task exposure (i.e., an equal number of similar trips in the same environment with equivalent ships), the accident rate for non-state pilots could be expected to be on the order of 10 to 20 times higher than that of state pilots.

Analysis

The study had a number of limitations that would inhibit any broad application of its results. In data comparisons, no tests of statistical significance were reported. For example, in the Key Factor Analysis Trend (Figure 15 in the Battelle report), the key factor trend is shown to be shown to be increasing, although no tests of statistical significance are reported.

The committee's review of the study's methodology showed that the number of trips and tonnages accrued to the non-state pilot group had been reduced. For instance, the report assumed that in-port trips related to cargo movement (including trips to and from sea, dock shifts, and movements to and from anchorages) occurred in some proportion to the trips to and from sea and that this proportion for in-port moves was the same for both pilot groups. This assumption is problematic, as there is no clear relationship between seagoing and non-seagoing trips (including anchoring, mooring, and docking evolutions). Furthermore, non-state pilots handle the bulk of such intraport transits. Inclusion of this data would have favored the federal pilots, increasing the number of tons carried, with no change in the number of accidents.

The report assumes that pilot task demands involved in movement of an average ton of cargo are the same for both state and non-state pilots. However, as the report notes, a transit is a combination of values and factors that determine the task demands of piloting. A measure of risk exposure for each pilot group would have provided a better assessment of safety and accidents per risk exposure mile.

Although screening of casualty data was intended to favor pilots not holding state licenses, the approach appears to have substantially favored state pilots, as Alaskan oil movements were not included in the analysis. The stated reason was that inclusion of the data would have skewed the analysis because of the large tonnage of oil moved in that trade. However, ship's officers with Federal First Class Pilot's Licenses or endorsements for pilotage routes used by the Alaskan oil coastwise trade, state pilots in Alaska and in West Coast ports, and independent marine pilots holding only federal pilot credentials but who pilot foreign trade ships in certain California ports (Chapters 2 and 3) all are involved in piloting ships carrying Alaskan oil to U.S. ports.

In addition, the report did not credit East Coast docking masters with the transport of substantial tonnages. This is relevant, because docking masters were assigned casualties but were not given credit for all transits in which no casualties occurred. Docking masters in some ports, by the nature of their work, would have been exposed to a significantly higher potential for groundings and allisions than state-licensed pilots, yet a full representation of their successful transits was not included (see Chapters 2 and 3). Additionally, the substantial number of intraport movements under the sole control of docking masters was not credited to their performance.

The "most influential and error-prone assumption," as characterized by the report, concerned the algorithms selected to allocate the Coast Guard's casualty data and the U.S. Army Corps of Engineers' tonnage data between the pilot groups. Casualty data were allocated on the basis of the information in the "pilot type" filed in the CASMAIN records. If the pilot type was designated as state, the data was so directed. All other pilot types, including casualties in which the presence of a licensed pilot was not indicated (shown as "none" in the data field), were directed to the non-state pilot group, an approach the report said penalized this group. Subsequent analyses were performed in the report in which the "none" cases were distributed equally between state and non-state pilots.

Another problem concerned the allocation of all foreign tonnage data to state pilots and all domestic, waterborne tonnage to the non-state pilots. In fact, state pilots handle a large portion of domestic waterborne commerce. This data allocation penalized the state pilots.

In view of these problematic assumptions, Leis (1989) recommended that state pilots, singularly or as a group, monitor and collect relative safety performance data. Improved safety data would overcome the basic deficiency of the report's analysis—the need to infer relative trips on the basis of tons.

1991 American Institute of Merchant Shipping Study

The objective of this study, conducted by Booz, Allen and Hamilton in 1991 for the American Institute of Merchant Shipping (AIMS), was to comparatively assess state and federal pilot safety performance between 1983 and 1988. Safety levels for each group were developed using the ratio of the number of dynamic casualties involving pilots to the relative risk faced by pilot group. Although addressing one of the limitations of the Leis (1989) analysis—lack of risk exposure as a normalizing factor—this analysis still relied on two surrogate measures to approximate risk: cargo tons moved by each group, and number of trips made by each pilot group within U.S. coastal ports. These denominators involve many of the limitations discussed in Leis (1989). Professional qualifications and performance of navigation technology were not assessed, nor were exposure to risk, performance of ship systems, or pilot performance in the towing industry.

Methodology

Marine pilots were divided into state and federal groups. Docking masters, although not technically operating under Federal First Class Pilot's Licenses or Endorsements while aboard foreign-flag ships or U.S.-flag ships under registry, were considered federal pilots for the purpose of the analysis. Results with and without docking-master data are presented. Data were not available that would permit a more definitive allocation of tonnages or trips between federal pilots and state-licensed pilots operating on a federal license. Docking-master exposure was estimated based on tonnages and operating practices in pertinent East Coast ports.

The methodology defined pilot groups by licensing authority and function performed. The report described and analyzed the differences among pilot types and accommodated these variations in the analysis. Both tonnages and trips were used in the comparisons; however, differences in operating environments were not considered. All casualty data used in the analysis were provided as appendices to the report. Only casualties where pilot error was a contributing factor were included, as determined by individual review of each casualty report on file with the Coast Guard.

Findings

The report contained two types of findings: those stemming from the composite analysis of federal and state safety performance nationwide and those resulting from port case studies. In the former analysis, the report found the following:

- Despite similar objectives, state and federal pilot systems exhibit major systemic differences. These include differences in minimum pilot qualification requirements, as well as in system oversight and governance.
- The number of dynamic vessel casualties involving all pilots decreased 21 percent (5 percent per year) between 1983 and 1988.
- The levels of risk exposure for both groups were *constant* with respect to vessel trips and *increased* with respect to cargo tons.
- The safety of both pilot groups improved measurably over the study period. By 1988, the overall U.S. pilot system (federal and state) was reported to be 40 percent safer than in 1983. By 1988, a dynamic vessel casualty involving a pilot aboard a self-propelled vessel occurred once every 10.5 million tons of cargo moved, or once in every 1,700 vessel trips, which accounted for the reported 40 percent safety improvement.
- Over the study period, the relative safety levels of the federal pilots were found to be greater than those of state pilots.

The findings in the individual-port case studies provided similar results:

- Varying levels of pilotage difficulty, rather than systemic differences between state and federal pilot systems, appear to be the primary reasons for differences in pilot safety performance across the studied ports.
- Relative to the national average, pilots operating in the port systems of New Orleans/Baton Rouge, Tampa, San Francisco, and Houston were more likely to be involved in a dynamic vessel casualty. In Houston, this ratio was slightly greater than the national average; in San Francisco, Tampa, and New Orleans/Baton Rouge, respectively, the ratios were two, three, and four times greater. However, the report noted that several factors affecting the difficulty of pilotage tasks (such as pilotage distance, channel width and depth, tidal currents, and traffic levels) were not accounted for in the measure of risk exposure employed.
- Analysis of pilot performance in port regions that were less safe than the national average indicate that both federal and state pilot groups contributed to the safety deficit. For instance, in Houston, Tampa, and New Orleans/Baton Rouge, pilots in both systems had poorer safety records than the national average. The report said these findings reflected heightened difficulties in pilotage tasks, rather than systemic problems.
- Comparative assessments of federal and state pilot safety performance at the port level produced mixed results. In New York and the Delaware River, the

reported data showed comparable safety performance between the two groups; in San Francisco, federal pilots were reported to be safer when tons moved was the measure of risk exposure (although this finding was complicated by the fact that domestic trip data appear to have been severely underreported in waterborne commerce data bases); and in Houston, Tampa, and New Orleans/Baton Rouge, state pilots were reported to have safer records. However, the report noted that 50 percent of the dynamic vessel casualties in the Gulf Coast were attributed to state pilots acting on federal licenses, thus doubling the number of dynamic vessel casualties in the federal pilot group and skewing the findings.

Analysis

The report provides a general baseline for assessing pilot performance and reasonably establishes that marine pilot performance is improving and that federal and state pilots have comparative safety records. The report does not distinguish between marine pilots and ship's officers piloting under a Federal First Class Pilot's License or Endorsement. Nor does it provide means to identify and determine universal and port-specific needs and alternatives for improving safety performance.

Perhaps the most useful finding of the AIMS report is buried in Appendix A, the port case studies, where the report concedes that "no uniform conclusions can be drawn from this analysis." This is, perhaps, the finding that can be drawn from *all* previous state and federal pilot comparative safety analyses. *Because of the lack of readily available and thoroughly reliable safety performance data, no uniform conclusions can be drawn.*

1991 Battelle Rebuttal to the 1991 AIMS Study

This 1992 report (Leis, 1992) attempted to resolve discrepancies between the findings of the 1989 APA report and the 1991 AIMS report with respect to federal and state pilot safety. In this study, Leis corrected a number of the difficulties noted for the 1989 report. Corrections were made with regard to the characterization of pilot groups; use of CASMAIN data; assignment of pilot error; inclusion of the Alaska and Hawaii oil trade; and use of a "trips" measurement to represent federal and state piloting exposure. Nevertheless, discrepancies between the two reports remained; even the 1989 data were reassessed with assumptions and definitions similar to those in the Booz, Allen and Hamilton/AIMS study. The differences are primarily due to varying interpretations of missing or incomplete data in the CASMAIN data base, as well as to differing philosophical approaches to data analysis. The overall result is a more cogent explanation of the rationale and data analysis in both the 1989 and 1992 reports; however, the rebuttal does not definitively resolve the safety debate. Instead, it illuminates the issues and data interpretations used in two prominent piloting safety studies, greatly assisting safety analyses to follow.

1993 U.S. Coast Guard Rebuttal to National Transportation Safety Board Petersfield/Bayou Boeuf Recommendations

The National Transportation Safety Board (NTSB, 1988a) recommended that the Coast Guard seek legislation to require all pilots aboard vessels engaged in commerce (foreign or domestic) on the navigable waters of the United States to have a federal pilot's license, which would be legally superior to all state-issued documents. In response, the U.S. Coast Guard initiated a review of marine casualties to determine the extent of pilot-related casualties. The Coast Guard sought to determine whether a relationship existed between the frequency of marine casualties and the license under which a pilot was operating. Marine casualties were defined as collisions, allisions, and vessel groundings occurring while a vessel was under the direction and control of a pilot. CASMAIN data for vessel casualties between 1984 and 1987 were used as the basis for this six page report.

Methodology

The analysis focused on self-propelled passenger, tank, or freight vessels greater than 1,600 gross tons that had been involved in a collision, allision, or grounding in a 10-port-area sample. The port areas used were

- Baltimore/Annapolis;
- Galveston/Texas City;
- Houston;
- lower Mississippi River (New Orleans, Baton Rouge, Port Sulphur, Avondale, Destrehan, Gramercy, St. Rose, and Good Hope);
- the Port of New York and New Jersey (New York, Port Elizabeth, Newark, Bayonne);
- Sabine River (Port Arthur, Sabine, Orange, and Beaumont);
- Delaware Bay and River (Philadelphia, Chester, Wilmington, Paulsboro, Camden, Gloucester City, and Marcus Hook);
- Columbia River (Portland [Oregon], Astoria, Longview, Kalama, and Vancouver);
- Puget Sound/Strait of Juan de Fuca region (Seattle, Tacoma, Blaine, Bellingham, Everett, Port Angeles, Port Townsend, Anacortes, Friday Harbor, Olympia, and Neah Bay); and
- San Francisco Bay region (San Francisco, Stockton, Oakland, Richmond,

Alameda, Crockett, Sacramento, Martinez, San Joaquin River, San Pablo Bay, and Carquinez Strait).

Examination of 516 marine casualty records for the 10-port-area sample indicated that in 130 cases listed the pilot's license was listed as "none" or "unknown." Further analysis allowed 91 of these 130 to be classified with respect to the type of pilot aboard. The Coast Guard's Exposure Analysis Project, which combines Army Corps of Engineer data for domestic U.S. trade and Census Bureau data for foreign trade, was used to determine the number of transits for the 10-port sample, for the years 1984 through 1987. (These transit numbers do not include shifts from piers and berths to other piers and berths within the same port.)

Findings

An analysis of the number of casualties per number of transits indicated that pilots operating under their state licenses are involved in 2.9 times more casualties than are pilots operating under their federal licenses. However, the report notes that pilots operating under the authority of their state license made more than 2.7 times more transits than did pilots operating under the authority of a federal license. Overall, pilots operating under their federal license experienced one casualty for every 851 transits, while pilots operating under their state licenses experienced one casualty for every 797 transits.

Usefulness

The Coast Guard found no statistically significant difference between the safety performance records of state- and federally-licensed marine pilots. The report concludes that the ratios of casualties per number of transits are virtually the same, and that "regardless of the type of license under which a pilot operates, the likelihood of experiencing a casualty is the same. [Therefore, a] pilot operating under one license type is not inherently safer than a pilot operating under another license type." Thus, this report uses CASMAIN data to support the argument that there is no difference in safety performance between state- and federally-licensed pilots. The report fills some of the important gaps in the CASMAIN data (e.g., pilot aboard, type of license held), performs an analysis based on adjusted CASMAIN data, and develops a simple exposure index (number of casualties over the number of vessel transits) for the 10 selected ports. The report provides a useful exposure baseline against which related statistical safety analysis can be compared.

Port-Level Safety Analyses

1991 Port Needs Study

The *Port Needs Study* (Maio et al., 1991) is a comprehensive, four-volume report containing a considerable amount of valuable information on exposure to risk, operating environments, vessel traffic service (VTS) technologies, VTS effectiveness, and benefits and costs. CASMAIN records were used as the exclusive accident data set. Near-miss and port-incident data collected by Coast Guard VTS systems and reported in summary format quarterly to Coast Guard Headquarters were not used.

The purpose of the report was to document the costs and benefits of potential Coast Guard-operated VTS systems in several deep-draft ports on the Atlantic, Gulf, and Pacific coasts. The federal Volpe National Transportation Systems Center conducted the study for the Coast Guard. The study began in February 1990, prior to the passage of the Oil Pollution Act of 1990 (P.L. 101-380); the report satisfied a requirement in the act for a study "to determine and prioritize the U.S. ports and channels that are in need of new, expanded, or improved vessel traffic service systems. …"

The report analyzes historical vessel casualties and their consequences and projected future vessel casualties and consequences for 23 study zones. *Navigational risk* was measured in terms of probabilities of collisions, rammings, or groundings and the attendant human and environmental consequences and economic losses. *VTS benefits* were defined as avoided vessel casualties and associated consequences, the latter being measured in physical units and assigned monetary values. *VTS costs* were defined as the initial federal investment for a state-of-the-art VTS system in each study zone and its annual operating and maintenance costs.

Methodology

The study methodology followed the following steps:

- define the study zones and subzones;
- analyze historical vessel casualties in those zones;
- forecast avoidable future vessel casualties in each study zone;
- estimate avoidable consequences in each study zone, associated physical losses, and the dollar values of those avoidable losses;
- estimate the cost of a state-of-the-art candidate VTS design for each study zone;
- compare the benefits and costs among the 23 study zones; and
- analyze the sensitivity of the relative benefits among the study zones to a range of uncertainty in key input variables.

Vessel exposure to a potential casualty was measured in terms of vessel transits; transits were measured by vessel type and size moving within each of the 99 study subzones, although not explicitly in terms of duration of exposure. For the years 1996 through 2010, transits were forecast by applying growth rates of cargo types carried by each vessel, and consideration was given to actual and prospective changes in vessel sizes throughout the study period.

Navigational risk was represented by the number of "VTS addressable" casualties per 100,000 vessel transits, by vessel type and size for each study zone. Using these measures, the report developed national average casualty rates for "VTS addressable" casualties, estimated by vessel type and casualty type. Historical casualty rates for the subzones with operating VTS installations were adjusted to account for the "beneficial" effects of existing systems. The casualty rates were then aggregated across all subzones and divided by the appropriate vessel transits to develop *national average vessel casualty rates*. However, incident data collected by Coast Guard-operated VTS units were not compiled and analyzed to validate the beneficial contribution of VTS systems or estimates of accidents that would be prevented.

Vessel casualty probabilities for each subzone were developed by modifying the national average casualty rates with risk-adjustment factors common to each subzone. These factors were generated by multiple regression analysis of statistically significant navigational variables common to all subzones. Subzone probabilities of casualties by casualty type, vessel type, and vessel size were then estimated by multiplying the national average vessel casualty rates by the subzone risk-adjustment factors.

Data

The primary data for the *Port Needs Study* were drawn from 36,000 vessel casualty records in the Coast Guard central file. These records represented vessel casualty records from the 23 study zones during the period 1979 to 1989. Of the total, 2,210 records were deemed "VTS addressable," defined as the following situations:

- open water collisions between two vessels (involving surprise, poor visibility, weather, or bridge team errors);
- certain overtaking situations;
- casualties at dredging operations or other work activity in the channel;
- certain casualties involving vessels at anchorage; and
- collisions when vessels were not anchored.

Vessel casualties deemed not "VTS addressable" included situations involving mechanical failures, fire or explosions; non-participating vessels (i.e., fishing vessels, or those less than 20 meters in length); casualties outside VTS range of surveillance; groundings or collisions in close-quarters situations such as dock ing, undocking, or maneuvering in a crowded anchorage; and incidents occurring with insufficient warning or lead time for VTS intervention. The VTS potential to intervene to prevent accidents or mitigate their effects on other traffic is acknowledged and is among the various benefits that were considered not to be quantifiable and are therefore not reflected in the cost–benefit analysis. VTS actions that influenced the outcome of incidents that did not result in casualties (Herberger et al., 1991; Ives et al., 1992; USCG, 1988a,b,c; Young, 1992) were not reflected in the cost–benefit analysis. For these reasons, the total potential benefit of VTS applications is likely to be somewhat greater than stated in the report.

Six primary data sources were used in this study:

1. CASMAIN records;
2. the Coast Guard's Personnel Casualty Database, which is linked to the CASMAIN data base;
3. the Coast Guard's Marine Pollution Retrieval System;
4. the pollution segment of the Coast Guard's Marine Safety Information System;
5. NTSB reports, which were reported to be helpful when casualties were not found in the CASMAIN data base but otherwise met the selection criteria; and
6. confirmation with Coast Guard offices in the study zones.

Findings

The findings were divided into a variety of topical areas (that is, avoided vessel casualties, avoided human injuries and death, and avoided hazardous commodity spills), and aggregate findings were presented that summarized the best sites for maximized VTS cost–benefit ratios.

Avoided vessel casualties. The study found that 980 casualties would be averted with the introduction of VTS, a 29 percent decrease in "VTS addressable" casualties. The ports that would benefit the most from VTS presence with respect to avoided vessel casualties included New Orleans (375 casualties prevented, 56 percent involving barge tows); Port Arthur (75 prevented); New York (73 prevented); and Puget Sound (60 prevented).

Avoided human injuries and deaths. If all 23 candidate VTS designs were implemented, a total of 138 injuries and 31 human fatalities were forecast to be avoided from 1996 to 2010. The ports predicted to gain the greatest benefit from the introduction of VTS included New Orleans (approximately 50 avoided deaths and injuries), Puget Sound (33 avoided), and New York (14 avoided).

Avoided hazardous commodity spills. In all, 100 hazardous commodity spills were forecast to be avoided; over 80 percent were predicted to be in the 10,000 to 750,000 gallon range. New Orleans was predicted to be the overwhelming beneficiary of the VTS implementation in this category, with 40 of the avoided hazardous commodity spills; New York (8), Houston/Galveston (8), and Puget Sound (8) were distant runners-up.

Avoided dollar loss of all consequences. The undiscounted 15-year total of avoided losses was forecast to be $1.98 billion, 60 percent of which would be accrued in New Orleans, Port Arthur, and Houston/Galveston. Mobile, Los Angeles/Long Beach, New York, and Corpus Christi benefitted from a combined 23 percent of these avoided costs. Of these dollar totals, hazardous-commodity-spill clean-ups accounted for 74 percent to 94 percent of the total. However, in Los Angeles/Long Beach, property value losses associated with spills reaching shorelines predominated, while in Houston/Galveston and Mobile, commercial fishing species losses and clean-up costs predominated.

In summary, the discounted value of projected VTS net benefits minus the discounted annual stream of VTS investment and operation and maintenance costs) for the period 1996 to 2010 were ranked by port areas in the order shown in Table D-1. A total of eight port areas were forecast to have negative net benefit: Jacksonville; Wilmington, North Carolina; Santa Barbara; Portsmouth; Portland, Maine; San Francisco; Anchorage/Cook Inlet; and Chesapeake Bay/Hampton Roads.

Various port-specific factors were adjusted to compensate for uncertainty. Those port areas with the highest adjusted net benefits were: New York; Tampa; Portland, Oregon; Philadelphia/Delaware Bay; Chesapeake Bay north/Baltimore; Providence; Long Island Sound; and Puget Sound.

Usefulness

Although not all ports were addressed, the report provides a strong basis for identifying port regions that would benefit from marine traffic regulation in the form of VTS. In addition to its serious treatment of risk analyses, attention to

TABLE D-1 VTS Benefits

Rank	Port	Net Benefit ($000)
1	New Orleans	479,449
2	Port Arthur	92,414
3	Houston	61,014
4	Mobile	48,141
5	Los Angeles/Long Beach	42,827
6	Corpus Christi	26,113
7	Boston	15,150
8	New York	9,036

statistical significance, and attempts to fit multiple regression lines to safety data, the report has special value for another reason—the wealth of data contained in appendices. Volume 1, Section 1, contains a thorough examination of prior U.S., European, and Canadian VTS studies; a review of the previous work indicates that the *Port Needs Study* is the most comprehensive quantitative analysis to date performed on this subject. Volume 1, Section 4, contains a summary of vessel traffic as well as an analysis of vessel casualties. Volume 1, Section 5, includes a detailed treatment of the algorithms and procedures used for forecasting vessel casualties and their consequences, including treatments of risk estimation, risk variables, and risk-variable coefficients used in the multiple linear and nonlinear regression analyses. The risk analysis model is also described. This detailed information is useful in normalizing the study's analyses, results, and conclusions across other related studies.

Volume II of the report provides considerable background that is useful in understanding local operating environments. Although not a comprehensive treatment of all operational considerations, such as local traffic patterns, pilotage practices (for example, harbor pilotage provided by docking masters), and safety needs which might not be evident in casualty data, the report nevertheless offers considerable background material that will be useful in planning VTS installations. Volume III, Section 2, provides valuable insight on potential VTS effectiveness that was not previously available; the expert opinions reflected a national cross-section of Coast Guard VTS expertise.

Pilot Governance And Administration

The committee observed that the issues surrounding pilot governance and administration have not changed much in the past 50 years. Several deficiencies in state and federal pilot administration and governance were noted in 1942, and several of these same issues were cited as contributory causes in recent National Transportation Safety Board marine accident reports (NTSB, 1986, 1988a, 1989a,b, 1990, 1991a,b, 1993).

For instance, in the collision between the *Petersfield* and the *Bayou Boeuf* tow, a contributing factor was the reported failure of the state pilotage oversight system to monitor the pilot's performance and to remove him from service or take action to correct his deficiencies (NTSB, 1988a). The NTSB found that the

> vesting of pilot oversight over New Orleans/Baton Rouge Steamship Pilot Association (NOBRA) pilots in a commission whose members are chosen for two-year terms solely from the NOBRA membership results in a conflict of interest which inhibits taking corrective action.
> (NTSB, 1988a)

Further,

> the failure to provide adequate oversight at the state government level, the lack of federal authority, and the exclusive control of the oversight of NOBRA pilots by fellow pilots results in the pilots not being held accountable for their role in the accidents. [In addition], the failure of the pilot commissioners to keep permanent, detailed records of the accident of each NOBRA pilot and the investigations of accidents by the commission tends to prevent the detection of poor performance among pilots, and inhibits implementation of remedial action to improve pilot performance.

Finally,

> the practice by the pilot commissioners in the *Petersfield* case of investigating each accident [to review] only the facts of that case, without reference to prior, similar accidents involving the same pilot, limits their ability to identify the root cause of accidents, to adequately evaluate the competence of pilots, or to detect a trend indicating deteriorating pilot performance.

The NTSB recommended to the Coast Guard that legislation be sought to require "all pilots of commercial vessels on the navigable waters of the U.S. to have federal pilot's licenses which would be legally superior to all state-issued documents.…" However, in supporting this recommendation, the report offers only a cursory examination of other state pilotage systems and federal pilotage administration, including discipline. Thus, the recommendation has been the source of much controversy.

The NTSB theme was echoed in a 1990 report of a board of investigation (USCG, 1990a), referred to as the "Henn Report" after Rear Admiral Arthur Henn, who chaired the board. The report, although not calling for a superior federal license, called for the "Commandant [of the Coast Guard] to promulgate regulations under 46 U.S.C. 8503(b) to require that a federally-licensed pilot control the movements of foreign vessels and vessels sailing under registry, unless they are required to have a state-licensed pilot aboard the vessel." In response, the Commandant re-ignited the issue of a superior federal license with the following reply:

> State pilot commissions are strongly urged to exercise disciplinary authority against pilots operating under the authority of state-issued licenses. If the necessary disciplinary authority is not available, consideration will be given to the creation of a federal license, superior to state-issued licenses, and subject to Coast Guard authority.
> (Kime, 1990)

The Henn Report also raised the issue of *docking masters or pilots* , and several witnesses before the Board of Inquiry that produced the report testified that they believed docking masters should be licensed by the Coast Guard and that the

Coast Guard should have the authority to discipline pilots, even those serving on foreign vessels and vessels sailing under registry. Several state and federal pilots that testified said that docking masters should be under federal or state regulation and subject to licensing requirements and disciplinary action. The Henn Report agreed with these opinions, concluding that "docking pilots should be subject to either federal or state licensing requirements" and that "all pilots should be subject to Coast Guard disciplinary action if they hold federal licenses."

The Commandant of the Coast Guard replied (Kime, 1990) to the Henn Report recommendation with the dictum that:

> A vessel should be under the control of a state or federally-licensed pilot, as appropriate, at any time when it is in pilotage waters and is not anchored or moored. (These conditions include mooring, unmooring, shifting berths and anchoring.) On this basis, a pilot who performs docking duties should be properly licensed, and, if not, [should] perform those duties under the supervision of another individual who does hold an appropriate pilot's license.

With this background, the following section reviews several studies of pilot governance and administration that were considered by the committee.

1990 Great Lakes Audit

Although navigation and piloting on the Great Lakes is outside the scope of the committee's assessment, the subject is of interest, because Great Lakes pilotage resembles state pilotage systems, although the system is administered by the Coast Guard. Thus, it provides a frame of reference for comparing pilotage models.

Under the Great Lakes Pilotage Act of 1960 (P.L. 86-555), foreign vessels that operate in designated waters in the Great Lakes/St. Lawrence Seaway system are required to take onboard, and be directed by, a registered pilot. The Department of Transportation (DOT) initiated a comprehensive review of Great Lakes pilotage in 1970, publishing the *Great Lakes Pilotage Review* in 1972 (DOT, 1972). The DOT later reexamined Great Lakes pilotage issues, producing the *Great Lakes Pilotage Study* (DOT, 1988). The 1988 report focused on operation of the pilotage system. It identified a number of improvements that could be made but found no significant safety problems. The report also identified significant questions regarding financial accountability and the effectiveness of the Coast Guard's oversight. An independent audit was recommended. (Procedures for rate setting and submission of rate increase requests for the Great Lakes Pilotage Program were not specifically enumerated by the Code of Federal Regulations [CFR] prior to 25 April 1990. Before this, they were left to the discretion of the Director of the Great Lakes Pilotage Program and the judgment of the Coast Guard's staff for the program.)

In 1990, the Department of Transportation's Office of Inspector General audited the Coast Guard's oversight and management of the Great Lakes Pilotage Program (DOT, 1990). (No prior audits of the program had been conducted by this DOT office.) The audit evaluated Coast Guard oversight and management of the Great Lakes Pilotage program, assessed the adequacy of the Coast Guard's review of expenses charged to the three pilotage pools, and examined the methodology used to establish pool rates. The Inspector General's report identified financial accountability problems involving fees charged by several pilot organizations and related Coast Guard regulation. The study also reviewed the selection and utilization of pilotage services and the accountability for the pool's assets and receipts.

At the time of the audit (1989-1990), approximately 60 civilian pilots belonged to the three Great Lakes pilotage pools and the Ninth Coast Guard District in Cleveland, Ohio, employed a staff of four civilians for oversight of the program, including the pilotage rate-setting process.

Findings

The study used subjective sampling techniques and performed such tests as were considered necessary to test the reasonableness of various expenses charged by the pilot groups. The report found that U.S. Coast Guard oversight of the Great Lakes Pilotage Program was inadequate, ineffective, and insufficient. The report indicated that U.S. Coast Guard managers had accepted, rather than questioned, the reasonableness of costs incurred by pilotage pools, and the Coast Guard overseers had a less than independent relationship with one pool's managing officials. The report did not identify any specific concerns with respect to the selection and utilization of pilotage services or the accountability for the three pools' assets and receipts. The study group recommended that overall responsibility for oversight of the Great Lakes Pilotage Program be transferred from the Ninth Coast Guard District to Coast Guard Headquarters in Washington, D.C. (this has since been accomplished).

The report found that all three Great Lakes pilotage pools had divested themselves of practically all assets and were leasing most of their office space and equipment. In addition, they were purchasing pilot-related services from support-service companies, most of which were affiliated or closely allied with the pilotage pools; pilots had beneficial ownership interest in these companies. There was little, if any, competition in selling goods and services among the affiliated or closely allied companies, and the resulting costs were passed along in the form of increased pilotage rates. Thus, the pools had little incentive to judge whether goods and services were actually needed, and if so, if they were obtained at reasonable prices. The report found that this situation and the unreasonably high expenses and pilotage rates could affect the use of Great Lakes trade routes.

In addition to recommending transfer of overall responsibility for oversight of the Great Lakes Pilotage Program to Coast Guard Headquarters, the report also recommended that the Commandant of the Coast Guard:

- ensure compliance with the requirement for pilotage pools to obtain annual independent audits of their financial statements, balance sheets, and expense and revenue sheets and a review of affiliated support-service companies' records;
- perform an annual evaluation of the reasonableness of and necessity for pool operating expenses;
- include in proposed pilotage rates only those expenses found to be reasonable; and
- obtain independent information on projected traffic on the Great Lakes and use this information in calculating pilotage rates.

This information should be retained for later rate recalculations.

The report provides a useful example of the negative effects of inadequate oversight and ineffective piloting administration.

1992 State of Florida Piloting Regulation Audit

In 1992, the State of Florida reviewed the regulation of marine piloting by the Board of Pilot Commissioners within the Department of Professional Regulation (DPR); the audit was conducted as part of the Florida Auditor General's 10-year schedule of performance audits (State of Florida, 1992). This audit reviewed the implementation of economic regulations and the need for economic regulation of pilots. The study is of interest because it presents an alternative view of one of the more structured and complete state pilotage systems in the United States with respect to the range of features identified in the committee's pilotage system model (see Chapter 2 and Appendix E).

As of November 1991, 92 state-licensed pilots operated in 13 Florida seaports. The DPR reported that state-licensed pilots handled 33,436 vessels in state ports annually. The department received 280 complaints on possible violations of piloting statutes and rules between January 1987 and August 1990. Of these complaints, 65 were judged by the department to warrant disciplinary action by the Board of Pilot Commissioners.

The Board of Pilot Commissioners oversees the regulation of harbor pilots in Florida. It is composed of five, active, licensed state pilots and five non-pilots appointed by the governor. Of the five non-pilots, two must be actively involved in shipping. The other three non-pilots must be independent of the piloting profession, the maritime industry, and marine shipping. The board's responsibilities include rulemaking for pilotage administration, determination of the numbers of pilots needed, and rate setting. In addition, the board determines if there is probable cause for disciplinary action, holds hearings on alleged violations, and takes action on violations as appropriate.

Methodology

The audit fieldwork that formed the basis of this report was conducted between October 1990 and April 1991. Auditors reviewed applicable sections of state laws and the Florida Administrative Code, which establish regulatory provisions governing piloting activities. Also reviewed were legislative budget requests, legislative reports, reports on board expenditures and revenues, DPR annual reports, and other documents describing the board's activities. Board members and staff were interviewed, as were staff from the Department of Legal Affairs and the legislature. Also interviewed were representatives from the Florida State Pilots Association and the Coast Guard.

To compare information about harbor pilot regulation in Florida with that of other states, legislative reports from other states were reviewed; staff responsible for harbor pilot regulation in Alaska, Connecticut, Hawaii, and the Coast Guard were also interviewed.

Finally, to evaluate the implementation of economic regulations affecting harbor pilots, auditors reviewed minutes of meetings of the Board of Commissioners, transcripts from rate-setting hearings, Coast Guard reports, and an opinion from the Federal Trade Commission concerning the effect of economic regulation.

Findings

The audit report was critical of the activities of the Board of Commissioners. The findings of the audit included the following:

- The board had not developed procedures needed to ensure that its decisions on the number of pilots needed and pilotage rates were fair and consistent.
- The board did not use a consistent methodology to determine the number of pilots needed in each port, nor had it developed "sufficient procedures" to ensure that pilot business expenses were complete and accurate.
- The board had also not developed a method to analyze the reasonableness of pilot business expenses and compensation.

In short, the audit found that "the current practice of limiting the number of harbor pilots may unreasonably and adversely affect the competitive market." Consequently, the audit suggested that pilots might be charging higher prices than would prevail in a competitive market. Further, the audit suggested that limiting the number of pilots might not be necessary to ensure the safety and availability of piloting services.

In response to these findings, the audit recommended that the Florida legislature consider eliminating the board's power to determine the number of pilots in Florida's ports. Further, if the state no longer limited the number of pilots, it might not be necessary to set the rates charged by pilots. The audit recommend ed that the Florida legislature set the maximum rate that could be charged by pilots in a port, thus fostering competition.

The audit also suggested that, if the state no longer limited the number of pilots, it might be necessary for the board to restructure the deputy pilot training program, as state pilots might be unwilling to train new deputies who eventually would become their competitors. The board was advised to study and revise Florida's pilot training program as necessary to ensure that all deputy pilots receive required training.

Even if the state continued to limit the number of licensed pilots at each port, the audit found that the board would need to improve the process for setting the number of pilots. A consistent methodology based on standards for the amount of pilotage work to be performed was recommended, as it would "enable the Board to insure that the ports have the number of pilots authorized to provide efficient piloting services."

The Florida Auditor General's report also addressed various means of regulating the piloting profession and suggested that economic regulation was not effective. The DPR dissented, maintaining that "economic regulation was the least restrictive and most efficient method of regulating the profession. …" The regulation issue was not resolved in the report.

Vessel Safety

The safety of vessels, especially tankers, has been the subject of a number of reports, many examining groundings and collisions and many in reaction to National Transportation Safety Board studies analyzing those collisions and groundings. Some of the board's findings with respect to tanker safety have been straightforward. For instance, in the case of the grounding of the *World Prodigy* (NTSB, 1991b), the NTSB recommended that state pilots be required to advise vessels in a timely manner of the location of the pilot boarding area, and to furnish the National Oceanic and Atmospheric Administration with information to update the *U.S. Coast Pilot* (NTSB, 1991b). In other cases, the recommendations with respect to vessel safety have been controversial; in the same *World Prodigy* case, the NTSB concluded that "had the WORLD PRODIGY been constructed with a double bottom or as a double-hulled vessel, the spillage of oil resulting from this accident probably would not have occurred" (NTSB, 1991b). Recent safety studies focusing on vessel safety are summarized in the following section.

1991 Nautical Institute Report on Management of Safety

The Nautical Institute published the *Memorandum on Maritime Safety* in 1982, which emphasized the need for proper enforcement of international conventions to identify and eliminate substandard ships. The Nautical Institute, in its

1991 report *Management of Safety* (Nautical Institute, 1991b), defined substandard ships as those "not meet[ing] the minimum standards laid down in the international conventions or, alternatively, which can be described as being inadequately found, manned, and stored for the intended voyage" (Nautical Institute, 1991c). The 1991 report found that, in addition to action to enforce international conventions, the eradication of substandard ships requires some action by ship's masters. The Working Group on Substandard Ships that authored this section of the report concluded that five positive steps could be taken by all masters joining an unknown ship:

1. determine whether the ship is generally seaworthy;
2. check the voyage planning;
3. ensure positive reporting (of procedures and competence on board);
4. undertake a more detailed condition report when there is enough time; and
5. make sure the company is made aware of any defects, and keep the personal and indemnity (P&I) club posted.

These steps are straightforward when masters join familiar ships; however, as the report notes, these can be radical steps when the ship is unfamiliar (Nautical Institute, 1991c).

The 1989 "Bell Report"

This Coast Guard report (Bell et al., 1989) identified factors that influenced operational safety of tank vessels and that increased the risk of pollution in U.S. waters. Based on field visits to several Coast Guard Marine Safety Offices (Long Beach, Seattle, and Portland), as well as a questionnaire to all officers in charge of marine safety at Coast Guard District offices and to Officers in Charge of Marine Inspection (OCMI), the report found that tank vessel safety was a composite of both material vessel condition and operational safety factors, including watchstanding qualifications, manning levels, crew fatigue, automation, bridge design, information displays, and economic pressures exerted by owner/operators. The study found that "no single factor, or specific combination thereof, could be used to determine the potential risk posed by a tank vessel." Further, the report found that

> Increased vessel size, sophisticated automation systems, quick in-port turnarounds, and limited Coast Guard inspection resources create formidable problems impacting the Coast Guard's ability to reasonably insure that U.S. ports are not exposed to a high degree of risk from tanker vessel operations.

As additional Coast Guard resources were unlikely, the alternatives were

- improved inspector qualifications and retention programs;

- revision of program requirements and inspection schedules to conform with program resources and current industry standards;
- reducing administrative burdens on inspection personnel;
- requiring greater responsibility and accountability on the part of industry to properly schedule and be prepared for an "inspection"; and
- requiring industry to provide suitable means for conducting internal cargo tank inspections.

Human factors and frailties were noted as significant factors in tank vessel operational safety. Consequently, the report recommended that the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers be signed, as it would "insure minimum competency." A similar recommendation was made by the National Transportation Safety Board (NTSB, 1991b) when it recommended that the Coast Guard

> …propose to the International Maritime Organization (IMO) that the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers, 1978 (STCW) be amended to require bridge resource management training for deck watch offices. …

Because the human element was "present in 90 percent of groundings and collisions, and about 75 percent in fires and explosions" (Bryant et al., 1987), the study group recommended that "the primary emphasis in preventing marine casualties should be on improving the ability of human beings to function effectively in the marine environment. Recommending additional equipment, too often the solution in the past, misses this point and provides a false sense of security" (Bell et al., 1989). Finally, the group found that

> The physical layout of a vessel's bridge ought to take into account the number of persons that will normally be on watch. Presently, the only criterion applied to a bridge drawing plan review is visibility; this is obviously of critical importance, but it does not encompass the totality of the problem. The layout of the bridge itself must be scrutinized during the design and plan review phases and must also be a factor in the Coast Guard's establishment of the vessel's manning standards.

Piloting Practice

Visual references and local knowledge are the backbone of piloting practice. Hederström and Gyldén (1992) report that as pilots began to use radar during poor visibility, they initially transferred visual techniques onto the radar scope, as plotting and parallel indexing techniques were not in use. In the 1990s, pilots were still applying visual techniques in radar navigation, perhaps because of poor initial or follow-on radar training, or because older pilots "do not want to change or learn new radar techniques." The same report describes piloting procedures used by the Swedish shipping company Wallenius Lines, which operates

30 large car carriers, and which has recently added two new ships and retrofitted eight vessels with fully integrated navigation systems. To emphasize the important role of pilots, the company has published a book explaining the bridge procedures policy (Wallenius Lines, 1991).

The handbook is given to each pilot station negotiated by the Wallenius fleet, as well as to boarding pilots; it describes how Wallenius wants to improve safety by implementing a pilot/co-pilot concept and how controlled turns are achieved. Hederström and Gyldén (1992) assert that on a ship with an integrated bridge, the pilot no longer will be the one and only person conning the vessel. Rather, in their view, the pilot will become a consultant with local knowledge who joins the bridge team. Further, in the berthing stage, the pilot will "still perform the shiphandling if tugs are required, but if not, the master in many cases will do the berthing himself. …, provided he is conversant with the local conditions and environment." Although operating companies that have invested in integrated bridge systems envision such changes in marine pilot roles, the Committee on Advances in Navigation and Piloting found that traditional pilot development programs and operating practices were not designed to prepare marine pilots for this role or to formally integrate them into the bridge team. Further, where legal requirements exist for pilots to direct and control vessel maneuvering, such requirements would seem to preclude integration of the marine pilot into the bridge team in a advisory rather than directive role. Some pilot organizations are working with operating companies to improve the utilization of integrated bridge systems.

Hederström and Gyldén (1992) also report that operational experience with integrated bridge systems and one-man bridge operations points to a number of factors that can significantly enhance safety:

- satisfactory ergonomic attention to bridge design and layout;
- careful and thoughtful passage planning;
- adequate and ongoing training in equipment, operations, emergencies, and management;
- preventive and continuing maintenance;
- ongoing professional development, including simulator, manned-models, and bridge team training, as well as bridge resource management; and
- safety audits.

These factors are consistent with the committee's findings in its assessments of current and past piloting practice.

Marine accidents, controversy over pilot safety performance, and the tension between traditional and innovative technologies and operating practices have resulted in a number of related studies. The major studies are reviewed in the following sections.

1989 "Bauman Report"

In July of 1989, the Commandant of the Coast Guard appointed a group to study pilotage in U.S. waters and to submit a report containing recommendations within two months (USCG, 1989). The report was a response to continued controversy over marine pilotage, which was invigorated by the grounding of the *Exxon Valdez*. The study group included three officers recalled from retired status and two Coast Guard civil service employees from Coast Guard Headquarters. It was chaired by Rear Admiral Richard A. Bauman. The study group met with individuals and organizations, including state and federal pilots, members of the maritime industry, and Coast Guard officials. Members of the group traveled to several ports and visited Coast Guard Regional Examination Centers. Three members visited Valdez, Alaska, to examine the local conditions and seek information from the Marine Safety Office, the Southwest Alaska Pilot's Association, the Vessel Traffic Service Prince William Sound, and from first-hand observation.

The group had eight objectives:

1. Determine the basis on which pilotage should be required, such as qualifications of the licensed personnel, the nature of the voyage, type of cargo, or other overall equipment.
2. Determine the extent of federal and state pilotage waters.
3. Determine which vessels should have pilots, and variations in these requirements due to vessel size, route, cargo, and other factors.
4. Determine requirements for pilot licenses concerning experiences, testing, and recency of service.
5. Determine the requirements for recertification, including familiarization.
6. Determine the pilot's responsibility aboard the vessel.
7. Determine the proper roles for federal and state governments.
8. Determine the navigation equipment and operational requirements for ships operating in approaches to and within pilot waters.

Methodology

The study group examined the laws, regulations, and practice of pilotage, as well as some significant casualties to tugs, ships, and barges in confined waters that were due to navigational or rules of the road errors. Some casualties occurred with pilots having the conn and others without. The group reviewed Coast Guard Marine Board of Investigation and National Transportation Safety Board actions connected with pilotage or navigation in confined waters without a pilot.

The group studied the efforts of various other groups within the Coast Guard headquarters that were examining any aspect of piloting in confined waters. The group also added an additional objective to their charge, to examine the naviga tional equipment and operational requirements for ships operating in the approaches to and within pilotage waters.

A public notice of the project was published in the Federal Register on 26 July 1989, and in all *Local Notice to Mariners*. The study group received numerous telephone calls, over 200 letters, three studies, and two videotapes in response to the notice. The majority of these responses were from state pilots and federal pilots. Other responses came from pilot associations, tug and barge companies, associations of ship owners and operators, oil companies, individual ship masters, other licensed officers, and state pilot commissions and boards.

Findings

The findings of the study group were divided into the eight study areas as defined in the group's objectives.

Pilotage Waters The group found that all large self-propelled vessels, vessels restricted in their movements (large freight or tank barges), and vessels carrying a large number of passengers should have a licensed pilot aboard. Thus, the group recommended that a legislative change be made to allow the Coast Guard to require pilots within the recently proclaimed 12 mile territorial sea rather than the former territorial sea limit (nominally 3 miles offshore). Further, the group "recommended [that] a pilot licensed for Prince William Sound be aboard every ship from a point somewhat offshore Cape Hinchinbrook and Seal Rocks through the entire length of the pilot waters" (USCG, 1989). In effect, a pilot would be required to be aboard from just seaward of the passages into Prince William Sound.

The study group recommended that the Secretary of Transportation:

- use the authority of 46 U.S.C. 8502(g) to designate all waters of Prince William Sound as an area on which a vessel must be under the direction and control of a pilot licensed under 46 U.S.C. 7101; and
- use the authority in 46 U.S.C. 8503 to require a pilot licensed under 46 U.S.C. 7101 to be on board vessels in those areas of Prince William Sound where a pilot is not required by the state of Alaska.

Small Vessel Pilotage The study group recommended that an amendment to 46 U.S.C. 8502 be made to allow the Coast Guard to develop regulations addressing small passenger vessels, where the requirement for all U.S.-inspected self-propelled coastwise seagoing vessels to carry a federal pilot had been "overlooked or unknown." Small passenger vessels, which can be over 200 feet in length and carry up to 1,400 passengers, are generally not required by their Certificates of Inspection to carry federally-licensed pilots.

The study group recommended that tonnage or length, or other criteria, be used to determine the requirement for pilotage of these vessels. The group further recommended that passenger vessels greater than 100 feet in length or carrying more than 149 passengers be required to carry a pilot. The study group recommended that the same requirement hold for small cargo ships of over 15 gross tons; this would include offshore supply vessels, some of which exceed 200 feet in length and have displacements of approximately 2,000 tons.

Because of the additional hazard to ports, facilities, and the environment that are posed by tank vessels simply by nature of the cargo carried, the study group recommended that self-propelled tank vessels over 50 meters (164 feet) in length be required to carry a pilot when underway in pilotage waters. The study group also recommended that regulations be further amended to clarify the status of docking pilots, specifying that docking pilots be required to have a pilotage endorsement for the appropriate route.

Requirements for Pilots' Licenses The study group recommended that service requirements for an original license or endorsement as a first class pilot be examined. The group found that the requirements in 46 CFR 10.703 allow applicants to qualify who have never supervised a navigating watch or conned a vessel. The holder of a master or mate license of inspected vessels and the holder of an Operator of Uninspected Towing Vessels (OUTV) license who has 18 months' service in the wheelhouse are also qualified after obtaining the required round trips. The study group believed that additional sea service would be a valid requirement and would not impose a heavy burden on any officer or operator who is qualified to be a pilot. The group found that it would be reasonable to require proof of six months' sea service under the authority of a mate's license or experience in a formal pilot's apprentice program. For the OUTV license, similar service requirements were recommended.

The study group further recommended that the Coast Guard not issue a pilotage endorsement to any license without a written test, including a chart sketch, and that the regulations in 46 CFR 15.812(g) be amended to require mariners to keep records to establish their service qualifications. These records were to be equivalent to the documentation of service required in 46 CFR 10.205(e)(1).

Requirements for Recertification and Familiarization The study group recommended that the provision for recency of service over a route be changed. Provisions in 46 CFR 10.713 allow certification on review of publications and charts to be accepted for "long or extended" routes in lieu of actual transits. The group believed that consideration should be given to amending the regulations to require at least one round trip over the pilotage route within the previous 12 months, either to retain license validity on that route, or to act as a pilot on that route. The group recommended deletion of the regulation allowing certification on review of charts and publications in lieu of actual transits.

Pilot's Responsibility Aboard the Vessel The study group concurred with several centuries of English and U.S. law on the subject of pilot responsibility aboard vessels, concluding that "the pilot is in full charge of the navigation of the ship, yet the master retains his overall responsibility." The study group also held that any pilot on a large ship should not be expected to perform both the navigation and watch officer functions; the group found that there should be both a pilot and a qualified watch officer on the bridge at all times when the ship is in pilotage waters. It was recommended that regulations be amended to include this requirement for self-propelled vessels over 1,600 gross tons.

The group acknowledged that small vessels following regular routes could be an exception to this rule, as these vessels traditionally have operated with one watch officer who also has pilotage endorsements for the waters traveled. The study group recommended that the pilot's share of responsibility for master–pilot conferences (which were deleted in 33 CFR 164) be reinstated; specifically, the group recommended the following language:

> The master or person in charge of the vessel [should be] informed by the pilot of any abnormal characteristics of the area to be transited and of non-routine maneuvers before the pilot makes them.
> (USCG, 1989)

Proper Roles for Federal and State Governments The study group did not concur with the National Transportation Safety Board in its recommendation to make the federal pilot license legally superior to any state license or commission. Instead, the group recommended that legislation be sought to extend the Coast Guard's authority over licenses it issues to any employment directly related to the qualification of that license. "While not making one license superior to another, it would remove the anomaly that when a state sees fit to discipline a pilot, perhaps even revoking his/her license, the federal license is untouched and remains valid."

The study group recommended that the Coast Guard open discussions with various state pilot commissions and pilot groups concerning revisiting the use of federal–state agreements for cooperative measures on pilot matters.

The study group also proposed that state waters where state pilotage is not required be identified in each Marine Inspection Zone and that the Coast Guard require a licensed pilot in areas where the state has chosen not to act. This proposal would cover pilotage requirements for vessels shifting from an anchorage to a berth, or between berths within a port complex, as well as occasions when a pilot is required but not taken. The group proposed that the regulation should require either a state- or a federally-licensed pilot.

Navigation Equipment and Operational Requirements in Pilotage Waters Because several ships have gone aground inbound to U.S. ports while enroute to the pilot station, the study group recommended that the Loran C coordinates of each pilot station be listed in the *Coast Pilot*. In addition, there have been a few casualties that, upon review, showed that a tug was ill-equipped to navigate properly or did not have access to recent information on the area being transited, presumably because the Navigation Safety Regulations contained in 33 CFR 164 apply to self-propelled vessels of 1,600 or more gross tons (the regulations do not normally apply to tugs, because they are usually less than 1,600 gross tons). However, tug and barge combinations of well over 1,600 gross tons could be operated legally without any required navigation equipment, charts, *Coast Pilot*, or *Notice to Mariners*. The study group recommended that consideration be given to amending the regulations in 33 CFR 164 to make at least some of them applicable to tug-barge combinations of 1,600 gross tons and over.

Additional Issues During visits to Regional Examination Centers and in discussions with Coast Guard officers serving as an OCMI, the study group found that the local knowledge questions in pilot's examinations were usually based solely on information contained in the *Coast Pilot.* Further, they appeared to be so general that they were poor indicators of actual familiarity with the port or place. It was recommended that these questions be reviewed and expanded to cover topics such as areas with unusual currents, changes of current during different tidal current stages, areas of frequent shoaling, and unusual local practices. It was recommended that each OCMI have a role in the development of such questions.

Usefulness of the Results

The requirements for this study group parallel the task of the National Research Council's Committee on Advances in Navigation and Piloting. The same eight issues are being examined. The background information contained in the Bauman report, tracing the history of pilotage, as well as the findings and conclusions are of interest to the committee. (Regarding pilotage jurisdiction, the National Research Council committee sought to determine whether there are waters for which pilotage should be required that currently are not subject to pilotage requirements. No problem areas were identified by the Committee on Advances in Navigation and Piloting aside from gaps in official accountability for docking and mooring masters and approach concerns raised by the Bauman Report and various NTSB accident investigations.)

1992 American Waterways Operators (AWO) Report to Committee on Advances in Navigation and Piloting

The U.S. barge and towing industry, comprising some 800 companies that operate a fleet of approximately 6,000 tugs and towboats and more than 30,000 barges, is far from homogeneous. With operations along the Atlantic, Pacific, and Gulf coasts, as well on the nation's inland waterways, the various elements of the towing industry differ significantly in the types of vessels utilized, the geographic areas served, the cargoes carried, and the backgrounds of people employed.

The American Waterways Operators' report (AWO, 1992b) focuses on pilotage aboard towing vessels, "which has been shaped by operational characteristics and a regulatory framework distinct in many ways from those which impact upon ship pilotage." Pilotage in the towing industry, explained as being quite different from ship's pilotage, is then explored.

The report describes existing procedures and policies for ensuring personnel competence in the towing industry. These include requirements for Coast Guard licensing, company criteria for selection to captain, the value of round trips in acquiring local knowledge, and the relative safety records of towing vessel captains and licensed pilots. In this last category, the report cites a 1985 study conducted by Temple, Barker, and Sloane (TBS) for Maritrans (then operating as Sonat Marine; TBS, 1985). The TBS study compared oceangoing barges of 5,000 gross tons or more (operating without pilots) with oceangoing ships of 1,000 gross tons or more (with federal pilots), analyzing collisions and groundings attributed to the personal fault of the pilot, master, or mate directing the movement of the vessel. The TBS report, which covered the period 1972 to 1982, is reviewed later in this appendix.

In comparing safety records of tug captains and state pilots, the AWO report cited an analysis of navigational safety on the Hudson River, conducted by AWO in October 1991, comparing the safety performance of state-licensed pilots and federally-licensed vessel operators (towing vessel captains and federal first class pilots) on the Hudson River between 1981 and 1989. Also cited were Army Corps of Engineer data and Coast Guard statistical analyses of collisions, allisions, and groundings involving state and federal pilots in selected U.S. ports. In each of these cases, the safety records of tug captains compared favorably with those of ship's pilots.

Findings

The report maintains that upgrading and maintaining marine safety necessarily involves ensuring that all those who navigate the nation's waterways are competent to perform their jobs safely. The report also asserts that there is a place in marine transportation for qualified navigators of all kinds: tug captains, ship masters, federal pilots, and state pilots. The report holds that no single class of mariner is a safety panacea; rather, navigational safety would best be served not by attempting to impose an artificial equivalency on mariners with such diverse functions, but by ensuring that each group is well-equipped to perform its particular job safely.

The report holds that "human factors are clearly a critical link in the marine safety nexus." Remedying the underlying cause of human error remains difficult, however. Simulator training is mentioned as being helpful, although "the towing industry's experience with simulator training is not yet far enough along for us to say without equivocation that this is the best means to assure proficiency." The report echoes a suggestion made to the committee by F. Eugene Guest of Marine Safety International/Computer Aided Operations Research Facility, that research be conducted to determine what constitutes mariner proficiency, how this level of proficiency can be attained, how proficiency can be validated or demonstrated, and whether demonstrations of proficiency required of airline pilots should be required of mariners.

Usefulness

The report provides an overview of variations in towing industry pilotage practice, with appropriately cited supporting data for its conclusions and recommendations. The report provided useful background information for the committee in its examination of pilotage practice in the towing industry.

1985 Temple, Barker, and Sloane Report

Temple, Barker, and Sloane (TBS) was retained by Sonat Marine to evaluate casualties of large (over 5,000 gross registered tons [GRT]) oceangoing tank barges, compared with those of ships over 1,000 GRT moving within U.S. harbors. The report (TBS, 1985) also provides an economic analysis of the additional costs of pilots compared with the cost structure of tank barge operations.

Data

The report is based on an analysis of collisions and groundings with damage involving vessels in waters where the Inland Rules of the Road applied, and where the personal fault of the master, mate, or pilot aboard caused the incident. This study covered the 11-year period between 1972 and 1982, examining Coast Guard casualty records for all types of vessels.

The casualty files of 93 tank barge incidents identified by the Coast Guard were reviewed at Coast Guard Headquarters. The files also were checked to find additional incidents. Each case was analyzed and then included in the data base if the following criteria were met:

- the barge was greater than 10,000 GRT, identifying the barge as primarily engaged in the coastwise trade;
- damage was sustained;
- the cause or fault was due to human, not equipment or material, failure;

- the incident was located within the jurisdiction of the Inland Rules of the Road, where pilotage applies;
- the incident was not a collision with an aid to navigation, as many of these are unreported and cannot provide a relevant comparison,;
- the incident was not administratively closed by the Coast Guard (that is, a Coast Guard investigation of the incident was still in progress); and
- the incident was not a duplicate report for a case already in the data base.

In addition to the 93 cases identified by the Coast Guard, 14 additional cases were identified and 74 other cases in the Coast Guard's files were excluded by TBS. Traffic information was calculated from waterway commerce data collected and maintained by the U.S. Army Corps of Engineers.

Findings

Evaluation of the Coast Guard data indicated that oceangoing tank barges over 10,000 GRT that had no pilots had a significantly lower incidence of collisions or groundings than did ships with pilots. In addition, tank barges greater than 10,000 GRT had equal or lower rates of incidents than did barges between 5,000 and 10,000 GRT.

The report found that the economic consequences of requiring pilots on tank barges would be to increase annual operating costs for typical tugs and tank barges by 1.7 to 7.1 percent, depending on the average voyage length and the number of port entrances and exits. It concluded, therefore, that one impact of pilotage would be to significantly reduce the net earnings of tank barge operators. Findings of the report were divided into four categories: casualty data, incident rates, costs of incidents, and costs of pilotage.

Casualty Data The report found that oceangoing tank barges over 5,000 GRT were involved in a total of 30 collisions and groundings between 1972 and 1982. Six of these barges were over 10,000 GRT. None of the tank barge incidents caused any fatalities or injuries, and the 30 tank barge incidents without pilots resulted in five pollution cases. In contrast, ships over 1,000 GRT were involved in 1,007 incidents during the same period, resulting in 51 fatalities, 67 injuries, and 19 pollution cases. No tests of statistical significance were run on these data.

Incident Rates The report found that tank barges greater than 10,000 GRT had about one-third the probability (0.0324) of U.S.-flag tankers (0.0895) of being involved in incidents when the exposure to risk is measured by the available years of service for each fleet. Tank barges between 5,000 and 10,000 GRT were found to have about two-thirds the probability (0.0588) of U.S.-flag tankers (0.0895) of incidents using the same measure of exposure to risk.

In the report, tank barges between 5,000 and 10,000 GRT and those greater than 10,000 GRT have about the same probability (0.00052 and 0.00050) of incidents. This level is reported to be approximately 25 percent lower than the probability for all ships (0.00069) when the exposure to risk is measured by the number of port sorties for each type of vessel. The report found that the average number of incidents during a 30-year life span is 1.7 for tank barges between 5,000 and 10,000 GRT, 1.0 for tank barges greater than 10,000 GRT, and 2.7 for U.S.-flag tankers.

Costs of Incidents The $52,742 average cost of damage from incidents involving tank barges greater than 10,000 GRT is less than half the $120,764 average cost of ship incidents. Further, the report found that the $117,253 average cost for incidents of tank barges between 5,000 and 10,000 GRT is nearly equal to the $120,764 average cost for ship incidents. The $26.58 average cost of incidents per port sortie for tank barges greater than 10,000 GRT is one-third the $83.79 average cost per port sortie for ships.

Costs of Pilotage The report found that the annual cost of pilotage for a tug-tank barge combination ranged from $72,750 to $289,500, depending on average voyage length and the number of port entrances and exits. These estimates assumed the average $750 pilotage rate per movement estimated by the Coast Guard. Actual annual costs of $96,738 to $350,520 were calculated by Sonat Marine. The additional expense for pilots was forecasted to increase total annual costs for a typical tug-barge combination by 1.3 to 5.5 percent based on the $750 Coast Guard estimated rate, and 1.7 to 7.1 percent based on actual cost data.

The report found that the annual pilotage cost for a 10,000-GRT barge would be 11 to 43 percent of the total annual crew costs of a tug-barge combination at the $750 rate. For a 90-mile voyage (about 45 percent of the company's long-haul voyages at that time), the annual cost of pilotage equals 43 percent of the annual crew cost, but pilots provide service during only 9 percent of the vessel's operating hours. Finally, the report found that

> The cost to the barge industry of pilots on board tank barges greater than 10,000 GRT during 1972 to 1982 could have been between 42 and 204 times the cost in damages suffered by those vessels during the eleven year period. (TBS, 1985)

Usefulness

There are three particularly useful parts to this report. The first is the Section 2 discussion of misuses of statistical measurements by the U.S. Coast Guard; the second is the Section 3 discussion of excessive costs of pilotage; and the third is the inclusion of all the data used in the analysis. The section on alleged *misuse of statistical measurements* by the Coast Guard centers on the methodology used to calculate the relationship between the size of a tank barge and the probability of a casualty. The calculation was reported to be based on the number of tank barges in each size classification as the measure of potential exposure to the incidents. The report noted two deficiencies in this approach. First, the methodology misrepresented the total number of barges that were in service during each of the years that the casualties were reported. A measure evaluating the number of years of barge service was suggested as an alternative. Second, the methodology misrepresented important facts affecting a vessel's exposure to incidents relevant to pilotage. The report proposed a different measure, employing the total number of port entrances and exits to establish exposure as the denominator of the risk-measuring statistic.

The section on the *excessive costs of pilotage* is of interest to the committee, as it is one of the few quantitative discussions of an often-cited criticism of the requirement for pilots aboard tank barges. In this analysis, the cost to the barge industry of pilots aboard tank barges greater than 10,000 GRT between 1972 and 1982 could have been between 42 and 204 times the cost in damages incurred by those vessels. The report held that, based on an average pilotage fee of $750 per movement, the industry would have incurred an annual pilotage bill of approximately $811,636 and would have paid $8.9 million during the period from 1972 to 1982. This estimate was said to understate the actual cost, because some ports established as many as three different pilotage segments, and the $750 per-call estimate did not include any costs for delays to the pilots or to the tugs and barges that had to wait for pilots. The $8.9 million pilotage cost was weighed against the total $316,450 cost of damages related to tank barges over 10,000 GRT and the fact that no injuries or loss of life occurred. This discussion quantified the costs involved and made no qualitative estimates of the costs or benefits.

Inclusion of the actual data used in the report's analysis facilitates replication of the study methodology as well as development of generalized actions based on the study's findings.

Analyses of Marine Accidents and Incidents

As early as 1972, the National Transportation Safety Board identified a number of factors that have played a role in collisions in the navigable waters of the United States (NTSB, 1972). Although human error is frequently cited as a probable cause in collisions, the board found that the underlying reasons for the error, the causal factors, are of greater importance when prescribing preventive measures. The board found that "there is a need for providing more effective assistance and tools to the mariner to enable him to cope with the increasingly complex decisions he must take." As a result, "multiple solutions" to the problems leading to collisions are necessary, as "no one particular solution will work in every location." However, the board found that the United States had lagged behind other countries in developing, experimenting with, and evaluating shore based collision avoidance systems. The 1972 report also cites shipboard collision avoidance systems, traffic separation schemes, traffic control systems with mandatory participation, position determination systems, and offshore marine terminals as having potential for increasing the safety of navigation.

A general overview of the role of the human element in shipping casualties is provided by Bryant (1991). The U.K. Department of Transport commissioned this effort by the Tavistock Institute of Human Relations to address "not just the immediate subject of *errors* but…the whole human *element* in accidents to ships." The findings, although not earthshaking, do clarify the issues involved in considering why the oft-quoted 80-percent human error rate occurs in shipping incidents and accidents.

A few reports have examined the task performance problems of shipboard personnel in order to assess their contribution to vessel safety. Some of these studies found that different task performance problems can be associated with different types of marine accidents (Cahill, 1983, 1985; Gates, 1989; NAS, 1976; Paramore et al., 1979; Smith et al., 1976). Many of these reports are dated, particularly with respect to navigation and piloting technology and bridge watchstanding practices.

In short, there have been no systematic attempts to incorporate the human element into the factors considered by those in charge of marine casualty investigations (Bryant, 1991). Bryant's analysis and suggestions are conventional. They include a systematic approach to identifying human error elements and interactions in accident reporting; near-miss reporting requirements; new approaches to files and records, as well as to the management of casualty information; and use of standard methodologies and checklists, as well as distributing "best practices" case studies.

1972 National Transportation Safety Board Report

Analyses of marine accidents and incidents, and recommendations for preventive measures, have been proposed and pursued for as long as ships and people have been going to sea. The National Transportation Safety Board (NTSB, 1972) described the marine environment and the need for safe navigation of vessels, relating the following:

> Progressive changes in the marine industry have triggered the introduction of new methods and equipment to assist mariners in safely navigating ships…The sheer number of vessels has increased significantly…[and] the size of vessels has increased sharply … Design characteristics have changed considerably during the past 10 years. The speeds of vessels have increased, and have reduced reaction times in dangerous situations. The higher speeds, in combination with improved loading and offloading capabilities, have reduced turnaround and transit times, which allow a vessel to complete a greater number of voyages within a specified time frame. Changes in traffic patterns… caused by variance(s) in

> the size and speeds of vessels and by the nature of (different ship types are also of concern).
>
> In the marine transportation field, the risk levels have risen during the past 10 years and probably will continue to rise in the future if no action is initiated to curb or reduce the causes of this rise. There are numerous factors which have caused the increase in risk levels. Many of these factors, such as increased speeds, higher traffic density, limited maneuverability, increased size, and greater numbers of vessels have already been mentioned. Another very important factor is the recent increase in types and quantities of hazardous and dangerous cargoes.
>
> (NTSB, 1972)

In short, the environment in which maritime navigation and piloting occur has not changed much in the past 20 years. The economic, political, environmental, professional, and safety concerns may have intensified, but the environment itself is as accurately described in that 1972 NTSB report as in any more current documents.

In its 1972 analysis, the NTSB described two facets to the problem of collisions of vessels: the number of collisions and the magnitude of potential losses resulting from the collisions. Solutions to the problem that were offered by the board, therefore, focused on attempting to eliminate or significantly reduce the number of collisions, the potential losses involved, or both. This report provides a useful primer for the committee for two reasons: it provides an overview of the committee's tasks, and it demonstrates that these issues, and approaches to their solution, have not changed dramatically in 20 years. Shipboard and shore-based automatic navigation systems, overloading of communications channels, VTS participation, VTS administration, position-determination systems, traffic separation schemes, and personnel training are all identified as issues in need of resolution.

Appendix E

Central Features of a Complete Pilotage System

The committee's examination of a wide range of pilotage systems in the United States, Canada, and Europe disclosed a number of features that are common to most pilotage models, although their actual form varies significantly. The composite model discussed in this appendix includes features that are essential to building, maintaining, and administering a complete pilotage system. Although these features would constitute a complete pilotage system, all components would not necessarily have to be carried out by a single organization. Some components may be most appropriately handled by a licensing authority, others by a pilot association or a third party; for some components, joint administration may be appropriate. Some components are interrelated, but all are discussed separately for purposes of clarity.

The central features provide a conceptual framework that can be used by pilotage administrators and pilot associations as points for comparison in assessing the completeness and, subjectively, the adequacy of their pilotage programs. Although this discussion is directed toward pilot systems, the basic features could also be used by shipping companies for the same purpose.

Professional Development

The primary feature of pilotage is professional competence. All other features provide support to ensure the efficacy of pilot services.

Recruitment

The objective of recruitment procedures is to provide the most suitable and, if prior maritime experience is required by pilotage authorities or associations, the most qualified applicants for training. The goal is to ensure that the individuals selected can develop the professional competence essential to effective piloting and that they have personal and professional integrity to justify the high level of trust and responsibility that others place on them. Considerable care is essential in choosing pilot applicants, because they will be expected to work independently, that is, without assistance from their colleagues while piloting, and because of the considerable personal and organizational investment of time and resources required for qualification in the profession.

An effective recruitment process needs to consider whether an individual has the physical condition, demonstrated mental abilities, interpersonal capabilities, visual-motor and practical skills (or potential), and maturity, as well as whether the individual is professionally suitable. These factors need to be assessed relative to the expertise that is or can be expected to be required. For example, the rapid move toward computer-based systems (such as integrated bridges with pilot expert systems) requires computer literacy with regard to the use and application of these systems, whether or not the pilot actually operates these systems or relies on the bridge team to operate them. Additionally, as more and more mariners enter the profession from nonmaritime countries or nontraditional sources, as vessel crew size is reduced, and as more-intense competition for cargoes is generated among world shipowners, more responsibility may be placed on marine pilots for the safety of vessel operation in port regions. Emerging electronic navigation systems for real-time determination of positions, tidal stages, currents, wind velocity and direction, and visibility may only be available on board some vessels. To provide this capability on all vessels, the pilot may have to be equipped with and operate portable computer-based equipment. Therefore, computer literacy or the potential to acquire computer literacy of the form needed is a new, nontraditional job requirement, which needs to be balanced with other screening factors.

Other factors in recruitment are the resources that will be committed to professional development. Will pilot skills be built from a basis of little or no maritime knowledge, or will development be subsidized by drawing on individuals with prior maritime experience and licenses? If extensive vessel maneuvering is associated with a route, as opposed to long transits with few course changes, individuals with extensive ship or boathandling skills might be desirable. Similarly, if tugs with tows are the primary clients, individuals with towing industry experience may be preferred. Thus, the tasks the pilot is expected to accomplish, the relative importance assigned to each screening factor, and the resources available for training determine the most appropriate recruitment sources.

Experience

Experience to become a competent pilot consists primarily of two elements.

The first is basic maritime knowledge. (Some of the components are discussed in the next section under "knowledge.") The second element is practical experience.

Basic maritime knowledge is gained either through:

- service aboard seagoing vessels or harbor craft such as tugboats or service craft (such as pilot boats); or
- attendance at one of the state maritime colleges or the federal maritime academy, followed by time at sea as a licensed deck officer, as an apprentice in a rigorous marine pilot development program, or both.

Basic maritime knowledge can also be obtained at one of the sea service academies, followed by service aboard Navy or Coast Guard vessels. Navy and Coast Guard sea service may provide, for some individuals, sufficient maritime knowledge to support a transition to commercial pilot service.

Practical experience leading to development of professional competency is usually gained during a pilot training program, as there is little opportunity for seagoing officers to handle their own ships in a piloting situation. An exception is experience as a tugboat master in the piloting waters that will be home grounds for the pilot. Tugboat masters routinely maneuver barges, provide assistance to ships in docking evolutions, or both. Another exception is Navy and Coast Guard sea service. Piloting and shiphandling is usually performed by ship's officers, even in those cases where a pilot is taken. Thus, there may be opportunities for some individuals to acquire expert shiphandling skills that could be adapted to commercial service through a pilot apprenticeship program.

In a complete pilot model, individuals selected for training as pilots would have attained at least a master's license (ship or tug, depending on pilotage needs), with several years experience as master. That experience could be aboard either large vessels in domestic or foreign trade or aboard towing vessels either engaged in harbor or offshore towing or in ship-assist work. If an apprenticeship program is utilized for producing pilots, then, ideally, the individual should have at least some advanced nautical education, preferably at a maritime college or academy.

Knowledge

The knowledge required to become a competent pilot consists of both the basic maritime knowledge that an individual gains from seagoing or towboat experience and the additional specific knowledge and experience required to become a competent pilot. The latter includes local expert knowledge about the pilot area and shiphandling theory.

If the individual selected to become a pilot does not have knowledge of ship bridge organization and procedures, then that knowledge must be gained through a training program that emphasizes that aspect. Individuals with experience on small vessels such as tugboats are usually somewhat deficient in this aspect of pilot knowledge when they enter the profession. On the other hand, individuals from the towing industry typically enter the pilot profession with greater-than-average practical experience in handling vessels in harbors.

Expert local knowledge of the pilot routes served is fundamental (IMO, 1981). Essential elements of information include:

- area geography;
- port and waterway configuration;
- hydrography (channel depths and widths, bottom configurations);
- hydrology and hydraulics;
- tides;
- currents;
- winds and weather;
- aids to navigation (including not only the aids themselves but also how to interact with them and the information they convey effectively);
- bottom composition (such as rock, mud, sand, or combination);
- marine facilities used by marine traffic;
- other traffic and operations (such as commercial fishing vessels, recreational boating, dredging, marine regattas);
- air draft (for bridges and overhead wires);
- communications;
- marine traffic regulation (such as vessel traffic services);
- local and seasonal traffic patterns and densities;
- ship maneuvering behavior for all vessels to be piloted, including hydrodynamic interactions with respect to other vessels, facilities, and channel bathymetry;
- advantages and limitations of various types of main propulsion and auxiliary maneuvering machinery;
- shiphandling (for piloting, anchoring, docking, and undocking, maneuvering with and without the aid of tugs, and emergency situations);
- tug control (for maneuvering assistance);
- use of ground tackle to aid maneuvering;
- navigation systems (traditional and electronic);
- radar systems (and where of utility, automatic radar plotting aids [ARPA]);
- marine and environmental-safety requirements; and
- other information of local significance.

Additionally, the pilot must have knowledge of both federal and state laws and regulations pertaining to the profession. These consist not only of those directly related to the profession but also those that can affect the pilot's actions, such as water, air, and noise pollution laws; quarantine regulations; federal regulations relating to vessels tests, manning, and outfitting; ship bridge visibility regula tions; and operational regulations or special orders (such as regulated navigation areas, Coast Guard Captain of the Port Orders, and state-imposed tug escort requirements for tankers).

Skills

The practical skills needed to become a competent pilot are those primarily related to shiphandling in general, shiphandling in narrow channels and shallow waters, and use of bridge resources (bridge team members) and navigation equipment in support of piloting tasks. Such skills must be attained through a professional development program. Both theoretical knowledge and practical knowledge must be acquired for a full range of ship types in order to apply practical skills effectively. Thus, the development program or training curriculum must integrate the two so that one reinforces the other.

Theoretical knowledge and practical knowledge about how to apply theory can be developed in several ways. Virtually every marine pilot association develops practical skills through a rigorous program of on-the-job training. Pilot candidates accompany experienced pilots as they perform their duties to learn the route, bridge procedures, vessel behavior, decision-making under various operating conditions, and other insights that are applied in developing and applying practical skills. When considered ready by senior pilots, the apprentice handles vessels under the tutelage of suitable experienced pilots. Some time is required to develop the required skill level—up to 3 to 4 years if the pilotage grounds are lengthy and complex. The time required also depends to some degree on the apprentice's prior maritime experience. Additionally, skills must be developed in maneuvering and using ship-assist tugboats for docking and undocking evolutions, even if this is not a service normally provided by the pilot. A pilot may be called upon to use tug assistance during an emergency and must be prepared to do so.

Generally, ship masters and other senior licensed deck department officers have limited opportunity to control ship-assist tugs or to develop, from a tug operators perspective, insight on the dangers involved in working alongside oceangoing ships. Therefore, an ideal pilot model would have apprentices spend time aboard various tugboats while they are assisting ships, observe these maneuvers from the ship, and become familiar with and practice tugboat control under the tutelage of an experienced pilot. Similarly, tug operators have little to no opportunity to develop insight on the bridge organization of an oceangoing vessel and on how to interact with bridge team members and the functions they perform. Thus, the pilot model needs to accommodate this gap in knowledge when tug operators enter the marine pilot profession.

Practical skills also include the techniques required to board and disembark from vessels using pilot ladders in various weather, sea, and visibility conditions. While pilotage grounds or areas vary greatly, one common thread is that the pilot always must be able to skillfully board a vessel and to debark the vessel on completion of piloting duties. This skill is attained by accompanying experienced pilots on-the-job and then by maneuvering vessels under tutelage to create a favorable lee for debarking. While this particular skill may seem minor, to the pilot it is probably the most dangerous part of piloting, as it relates to individual safety and health and to the safety of the pilot vessel that comes alongside. Sometimes the environmental conditions are so bad that disembarking an outbound vessel would be life-threatening to the pilot and pilot boat operators. In these cases, pilots must stay aboard to the ship's next port of call.

Skill must also be developed in using various navigation equipment on the bridge. These equipment includes radar, ARPA, automatic steering systems, thruster controls, bridge-control devices for propulsion, radios, internal communications systems, depth-finding equipment, Doppler speed readouts, and emerging electronic equipment such as electronic charting systems. The pilot must also be able to operate basic equipment such as radar. It is impractical for the pilot to be familiar with all equipment configurations and features, however. For example, there are just too many variations in ARPA systems for the pilot to become proficient in the operation of each. Instead, the pilot must understand the capabilities of the equipment and whether it is being correctly used by the bridge team to support the pilot as he or she provides expert direction and control of the ship's movements.

Another way to develop practical knowledge and skills is through use of computer-based or manned-model marine simulations. Because these simulation programs usually last only about a week, there is little time to develop practical skills as might be acquired through more frequent use of this training medium, as in aviation (see Guest, 1992a). Preliminary research literature that suggests but does not fully prove the value of simulation for building skills that transfer effectively to actual operations (Haapio, 1992; Hammell et al., 1985; Kayten et al., 1982; Miller et al., 1985; Multer et al., 1983; O'Hara and Saxe, 1985; Schilling et al., 1985; Webster and Young, 1993). That pilots can benefit from simulation was demonstrated by Hammell et al. (1985).

There is a growing belief in the maritime community that simulations can at least provide familiarity and basic and refresher training with the tools of the trade that can then be turned into practical skills through on-the-job experience. For the most part, simulation is not used as an entry-level training medium for marine pilots, although several U.S. marine pilot groups have begun to use simulations as part of their apprentice programs. Such uses have included preparation of pilot apprentices for emergency shiphandling decision-making. But, marine pilot associations using simulations have done so primarily for continuing professional development. Ten possible pilot-training modules for computer-based simulations were identified through research conducted by the U.S. Maritime Administration (Box E-1). While substantial progress has been made in computer-based simulations, not all pilots are convinced of its value in develop ing practical skills for their work. They question the accuracy of its replication of actual conditions, either representative vessel types, sizes, and maneuvering behavior or operating conditions in narrow channels, shallow water, and river environments.

BOX E-1 CANDIDATE MARINE PILOT SIMULATOR-BASED TRAINING MODULES

- Pilot procedures
- Decision-making
- Rules of the road
- Vessel-to-vessel communications
- Advanced vessel-to-vessel communications
- Navigation in restricted waters
- Vessel characteristics
- Shiphandling
- Emergency shiphandling
- Advanced instrumentation

Source: Gynther et al., 1985

Crisis management experiences have shown that learning how to respond to a crisis *during* the crisis is not only less than ideal, it also greatly increases the probability that decision-making will be flawed. A licensed marine pilot is expected to have, for example, all the shiphandling skills needed to respond to a breakdown by another vessel that blocks a channel. However, a pilot's normal experience would not necessarily provide the mental preparation necessary for time-critical decision-making under stress (see Gates, 1989; Huffner, 1976; NTSB, 1989a, 1991a; Plummer, 1966). Similarly, taking a ship with uncertain handling characteristics in shallow water into a confined channel, or meeting another vessel there for the first time, would severely challenge even the most seasoned mariner (Plummer, 1966). Marine simulation is one means to practice emergency procedures so that they become instinctive and to provide a sense of the time frame in which decisions need to be made in order to be effective. Marine simulation could also be used to determine whether certain interactions should be attempted such as meeting another ship in a narrow channel (NRC, 1992a), and also to improve the skills necessary for successful maneuvering. Each use could reduce the potential for marine casualties.

Continuing Professional Development

Although marine pilots in the United States generally form close-knit professional associations (which are, in effect, state-regulated or locally regulated, limited-access businesses), their profession is nevertheless characterized by independent service. Rotational assignments are used to ensure fairness in assign ing piloting jobs and to provide adequate periods of rest. Rotations generally expose pilots to changes in marine transportation, including new propulsion and steering systems, navigational aids, electronic navigation systems, and so forth. However, rotational assignments and shipping trends in any particular pilot service area do not by themselves provide complete certainty that pilots will keep pace with all changes in operating practices, technology, rules, regulations, and official policies. A complete pilot model would therefore include means to ensure that a marine pilot's knowledge and skills remain current with developments in the shipping and towing industries so that their service accommodates marine transportation needs.

Options for continuing professional development include organized meetings to provide updates on changes in transportation and marine safety regulations and debriefings on lessons learned from marine casualties; other information transfer opportunities; skills enhancement and development opportunities; refresher training; and instruction in emergency procedures. Some options are suited to the classroom; others may be better suited to field work or marine simulation. No one approach provides the full range of professional development. Simulation facilities provide some capability to refine or refresh some shiphandling skills; when simulation is coupled with classroom training, theoretical knowledge can be increased or refreshed as well.

Manned-model simulations can be used in real environmental conditions to refresh shiphandling skills for particular types and loading of vessels in generic situations. The knowledge and skills are transferable to practical situations by interpolation. This form of simulation can also be used to introduce pilots to types and sizes of vessels not normally piloted, again, under real environmental conditions. Effects of scaling factors on transfer of training, and value added to piloting skills, are not certain. However, many pilots who have participated in manned-model simulations report that the experience provided insight or refreshed awareness of shiphandling theory and practice. It also introduced them to techniques that were unfamiliar or with which they had limited experience.

Computer-based full-mission simulations can be used in continuing professional development programs for the training areas indicated in Box E-1. However, the limitations discussed earlier apply. There is also the question of the relative value of manned-model simulations versus that of computer-based simulations for development of shiphandling skills. Manned-model training is limited to the physical hull forms that are available, the physical limitations of the lake or basin used for the training, and the environmental conditions at the time (the facilities are outside). Manned-models do, however, provide a reasonably realistic anchoring capability and also allows the operator to sense and experience the forces at work on the hull and how the vessel reacts to them. Computer-based simulations are limited by such factors as the mathematical ship models and the vessel hydrodynamic, port, and environmental data available to drive the simulation. However, as these are software and data availability rather than hardware factors, there is somewhat more flexibility in developing port- and vessel-specific simulations when using computers. Additionally, it is possible to simulate tug-assist operations at some simulator facilities. But, resources to develop new port-specific simulations are a limiting factor. The cost of the training also can be a limiting factor. Computer-based simulations are also limited in their capability to provide realistic anchoring scenarios.

Development and refinement of shiphandling skills for licensed pilots is already accomplished to some degree using manned-model simulations, and, depending upon the fidelity required, computer-based simulations. Other potential uses for part- or full-mission computer-based simulations include route familiarization, development of pilot candidate and ship's officer shiphandling skills, bridge team training, and advance preparation for handling vessels or unfamiliar classes of vessels.

Personal computer (PC)-based simulations for marine training are an innovation increasingly considered by the Coast Guard for possible use in marine licensing (ECO, 1987; USCG, 1993f). However, the value of PC-based training for selected piloting tasks, route familiarization, and for practice or mental rehearsal has not been established either through field applications or experimental research. The state of practice of PC-based simulations is rapidly evolving as manufacturers search for training and real-life applications. Simulations have been incorporated into PC-based interactive multimedia instructional presentations under instructor guidance, principally by the U.S. Navy, and into rules-of-the-road applied training (McCarthy, 1993; USN, 1992). PC-based training systems for navigation, radar plotting, and communications tasks are available and in use by some training facilities. PC-based maneuvering simulations have also been developed and have been advertised as decision support aids for real-life operations. Although the computational power of current generation microcomputers permits the use of sophisticated mathematical models for ship behavior and high definition graphics, their ability to produce accurate vessel trajectories and induce real-to-life human responses is constrained by the limitations that also affect full-mission ship bridge simulations. Additionally, PC-based simulations lack bridge instrumentation and do not reproduce the bridge operating environment, including interactions among bridge personnel. PC-based training systems potentially might be useful in continuing training and evaluation as the application of this technology to marine training and licensing matures.

A complete pilot model would include pilot participation in a program of continuing professional development combining the various needs and approaches just discussed. Such programs could either be required by licensing authorities or implemented voluntarily by pilot organizations as a professional service to their members (a formal requirement may be necessary in some cases to motivate and ensure organizational, industry, and financial support). Regardless of how it is implemented, the program should be routinely scheduled at a frequency sufficient to ensure that all pilots are kept abreast of technical, operation al, procedural, and legal developments, and that practical piloting skills remain at or above acceptable levels.

Proficiency Validation

Means are needed to determine or validate the professional competence or proficiency of:

- pilot apprentices seeking licensure;
- candidates for pilot route extensions;
- pilot preparation for routes infrequently traveled;
- pilot upgrading to vessels of different types or sizes;
- pilot preparation for new categories of vessels or newly constructed channels;
- pilot resumption of service after a an extended period out of service; and
- determination of pilot fitness to continue service.

This list demonstrates that the need for proficiency validation extends beyond pilot apprentices or junior pilots moving up to senior pilot status (that is, full branch pilot or equivalent). There is a need to ensure the skills of senior pilots as well.

The methods available for proficiency validation include:

- subjective written examinations;
- tutelage (including observation and evaluation);
- check rides (under observation by a pilot assessor or examiner qualified and approved or certified for this service);
- in-service evaluations (by a qualified pilot examiner); and
- marine simulation.

Not all individuals may be able to convey their practical skills well using written responses. Some indication of proficiency is possible through "expert accounting," that is, oral responses to various scenarios by the individual being assessed. The technique has limitations. Additionally, deficiencies in practical skills are difficult to detect unless actually observed.

The scope of validation substantially exceeds common practice, except for apprentice programs and those pilot systems that embrace the concept of progressive advancement. In the latter case, progression typically involves advancement to ever-larger vessels (length and tonnage) after route experience and piloting and shiphandling skills are reinforced through experience on small vessels. Few pilotage systems have check ride programs, although this is common practice for Panama Canal pilots during their first two years of service. Verification of proficiency in handling vessels of each size is not common practice. However, proficiency can only be determined by evaluating the actual piloting and handling of each size or category of vessel, or perhaps through observation of pilot performance during a marine simulation. neither approach is common practice in U.S. pilotage systems, although a few U.S. and foreign associations are advancing in this area. A complete pilotage model would provide means to ensure the professional competence of pilots at the highest level served and to maintain the level of competence that is necessary.

Recency

Recency of service on pilotage routes is imperative to ensure that

- the pilot keeps abreast of changes that have occurred along the route; and
- skills have not become rusty through either long periods between active service or limited opportunity to practice skills on certain types, sizes of ships, or routes.

How frequently a pilot should provide service to particular vessels and routes varies according to a wide range of operating factors associated with each port (see Chapter 4). Pilots need to experience the full range of operating conditions, including seasonal variations, for the vessels to be piloted, either as an observer or as a pilot. In the committee's opinion, this experience is needed on an annual basis. More frequent piloting experience may be necessary in some operating environments, because changes may occur more frequently than annually. For example, visual cues can change quickly in areas undergoing intense development. In the absence of fundamental research to guide such determinations, local expertise would be required to establish reasonable recency requirements.

Accountability

Marine pilots have responsibilities to the piloting profession (to maintain its integrity and credibility), the ship (including the master, crew, owners, and cargo owners), colleagues (both as practitioners and as members of a pilot association), port authorities (who depend on the efficacy of the pilot's service), governing authorities, and the general public (for public and environmental safety). Given the weight and importance of these responsibilities, pilots are held accountable for the services they provide in order to maintain the credibility of the pilotage system itself.

Certification/Recertification

Certification is a voluntary act by an individual and a certifying entity that, in some organized fashion, measures an individual's qualifications to perform a specialized function. No authority or privilege is conveyed, although custom or market forces may require or necessitate that an individual obtain certification. Accreditation is similar to certification, except the term is applied to institutions and programs and not individuals (Anderson, 1992). Certification could be applied within pilotage systems as a means to demonstrate continuing development short of actual licensing requirements. For example, a pilot could seek certification for different types of navigation equipment. Although certification programs are traditionally voluntary, certification criteria that establish professional standards are sometimes institutionalized into regulations or licensing programs to make the application of such standards universal (see Chapter 3).

Certification requires individuals or organizations qualified to conduct the certification. Many marine pilot associations certify their own pilot apprentices using internal professional development programs. Some state pilot association apprentice programs are officially sanctioned by their governing authorities, but few are formally accredited. Ten pilot-apprentice development programs are, however, approved by the Coast Guard as equivalent to actual sea service in building the service and route experience required to obtain original Federal First Class Pilot's Licenses or Endorsements. These approvals are subjective and based on recommendations of the pilot associations. Because certification is not widely used in developing professional competence for other aspects of navigation and piloting, implementing certification within pilotage systems would also require the establishment of qualified certification authorities.

Licensing

Licensing is an authorization in the form of a license granted by a government or an entity to perform or provide a function or service. Licensing is rooted in a government's police powers and is traditionally applied for the purpose of protecting public health, safety, and welfare. Licensing conveys a legal authority to engage in a function or service (Anderson, 1992). In pilotage, licensing is also applied to protect property and the environment. Inherent in marine licensing is the concept that an individual is professionally competent to perform under the license granted and is accountable to the licensing (that is, governing) authority for competent performance.

A complete licensing program would include prerequisites in terms of service and training as well as theoretical and practical examinations and chart sketches to demonstrate route knowledge. At present, only theoretical examinations are conducted in the federal and some state pilotage systems. No formal practical examinations are given to determine proficiency in piloting and shiphandling. However, in many state pilotage systems, an individual may not sit for a written examination until pilots within the association are satisfied that the apprentice has the necessary practical skills. This approach is an alternative to a formal test of proficiency to the degree that proficiency validation by pilot associations (or third parties) is credible and acceptable to licensing authorities.

Exemptions

Traditionally and in theory, masters are considered the most experienced shiphandlers for their vessels because of extensive familiarity with them under a wide variety of operating conditions. Assuming that the master (or senior mate) could acquire sufficient expert knowledge of a pilotage route, the master or mate could effectively pilot his or her vessel on it. Exemption programs such as those found in the Netherlands and the United Kingdom recognize this, often as an economic service to port-state shipping companies, by authorizing the master or mate, after suitable local qualification, to serve as the vessel's pilot. In such cases, a certificate, license, or license endorsement is issued to formalize this permission. However, modern manning and operating practices and port-state operating requirements may or may not result in the master (or a senior mate) acquiring a high level of shiphandling skills or pilotage route knowledge.

In Europe, where exemptions are generally an option for masters and senior mates of member states of the European Community, these exemptions are limited to a specific vessel (or sister vessel) and a specific route. Qualification requirements usually include a minimum number of trips, very recent experience on the route, a written examination, and a field test. Because port-states or federations of mostly port-states (such as the European Community) do not control the qualification of masters and bridge teams of foreign-flag ships, they do not authorize the masters or mates of such ships to pilot their vessels where pilotage is required.

Professional Oversight

Because pilots provide their service independent of other pilots, their performance is not observed except by personnel aboard the ship piloted, and, to a substantially lesser degree, by other pilots aboard other vessels encountered during pilotage jobs. To ensure that pilot performance meets at least minimum standards and to provide a means to detect problems for which corrective action can be taken, professional oversight is needed within the pilotage model. One option is maintenance and analysis of complaint or accident records to identify individuals whose names appear more frequently than is acceptable or who have one or several reports that merit specific attention. Another option is field checks by appropriately qualified pilot examiners. Because of the need to maintain integrity and credibility of oversight, and to preclude difficulties in professional relationships between individual pilots, formal oversight may be best accomplished by governing authorities or suitable third parties. However, pilot associations and their members have a moral and perhaps a legal responsibility to ensure that the safety performance of members meets acceptable standards. Professional peer pressure to perform pilotage services at the optimum level of safety is a traditional and integral part of established associations. Pilots also could provide, for example, some form of professional screening, perhaps as a component of their continuing professional development program, to assist their colleagues whose performance may have deteriorated (a condition that could go undetected without occasional performance assessment) but could be restored to acceptable levels.

Incident/Accident Investigation

Credibility of pilotage depends in part on investigating incidents and accidents to determine their cause, so there is a factual basis for corrective action. Such action may involve either pilot performance or other components of the marine navigation and piloting system that may have been causal factors. A complete pilotage model would, therefore, specify means for collection of incident and accident data, including testimony. It would also specify provisions for analysis and corrective action based on the results.

There is a distinction between incidents and accidents, although both should be reported and investigated to determine what corrective action might be appropriate. Incidents include numerous events, often minor in scope, that result in no adverse consequences, either to the vessel or port infrastructure in term of physical damage or to personnel in terms of injuries and non-life-threatening events. Incidents, as used here, also include events with damage or which cause effects that are below thresholds recorded as marine accidents (referred to as marine casualties under Coast Guard reporting requirements). Incidents include a line parting during docking or undocking without injury, loss of propulsion or steering without a grounding or collision, radical maneuvers to avoid recreational craft, and wake damage. Some incidents are so minor as not to merit further attention. Other events (such as loss of propulsion), individually or in the aggregate, may provide valuable insight on the performance of pilots, vessels, and the marine traffic safety system (Ives et al., 1992; Young, 1992). A complete mode l would provide means for reporting and analyzing incidents, so that incident-specific needs for improvements or corrective action can be identified.

Accidents are easier to define than incidents. They involve certain types of events, such as collisions and groundings. Certain events such as groundings may need to be reported regardless of whether damage occurs, because they can provide strong indications of piloting or vessel system problems. Other types of accidents may be governed by reporting thresholds, depending upon the safety objectives being served. Effective investigation of marine accidents requires an in-depth understanding of vessel systems, human systems, waterways management, and marine pilotage, so that both proximate and underlying causal factors can be determined. Proximate causes of accidents can generally be determined through analysis of the facts by knowledgeable individuals, and through expert forensic analysis (Gates, 1989). However, underlying causal factors are more difficult to ascertain, because (1) accident data typically emphasize vessel rather than human systems, (2) the data are often incomplete or subjective, and (3) investigators are typically not prepared to conduct expert in-depth analysis. A complete pilotage model would provide for multidisciplinary assessment when the nature of an accident indicates the need for in-depth analysis. Such an assessment could be conducted by a specially constituted board of experts, a third party such as a marine surveyor, appropriately trained investigators from pilot associations or governing authorities, or some combination of these.

Safety Performance Monitoring

Related to *professional oversight* and *incident/accident investigation* is the monitoring of safety performance of pilots, vessels, and the marine traffic safety system in the pilotage area. Performance problems may be too subtle; intermittent; or, in the case of individuals, masked, and thus not always detectable through investigations of specific events or through periodic personal observation or evaluation, either in the field or through simulation. For such cases, a dedicated program of long-term performance monitoring is necessary. Such programs could be accomplished through collection and analysis of performance data, with incident and accident reports forming a principal resource. Compilation of complaints received about individual or vessel performance can also provide indicators of problems needing further assessment. To assist in this process, key data fields could be entered into an automated data base, which could then be consulted for frequencies and trends (see Young, 1992).

Discipline

Discipline takes two basic forms—professional discipline and official discipline after an incident or accident. Professional discipline is developed through the *professional development* features of the pilotage model, professional peer pressure, and professional oversight. A complete pilotage model, by establishing effective means to validate and oversee pilot performance as described earlier, provides the means for early detection of many performance problems before they become critical and contribute to a marine accident. Considering that pilot expertise takes years to develop, the pilot model would, as an objective, seek to correct deficiencies, rather than remove the individual, in order to preserve and enhance the pilot as a valuable asset in the local marine traffic safety system. For example, remedial or refresher training, or additional experience on smaller vessels, could be used to correct weaknesses in professional skills. The pilot model would establish a similar approach using similar techniques for rehabilitation of pilots involved in marine accidents, insofar as this is appropriate to the circumstances. A pilot who has been involved in an accident (to the degree that lessons are learned and performance deficiencies are constructively corrected) may become more valuable as a special asset to the local system.

A complete model would also provide for punitive action as a measure of last resort if rehabilitation were not feasible or if incompetence, willful negligence, or substance abuse were involved. In these cases and in addition to possible corrective actions, the pilotage model would provide options for fines, suspensions, and license revocations. Given that discipline can be a career-ending event, the pilotage model would also provide for hearings, review, and appeals processes where disciplinary proceedings could result in corrective or punitive action.

In conjunction with discipline, a complete pilotage model would address liability. Because of the nature of their work, marine pilots are continuously exposed to considerable operational and economic risk. Liability insurance for most pilots is either not available or not affordable. To the extent that the integrity of pilotage might be jeopardized by pilot liability for marine accidents, the pilotage model would need to consider limits on liability at a level agreeable to the marine pilots, shipping interests, and governing authorities in the public interest.

Local Involvement

Pilotage is area-specific. As such, pilotage requires not only that the pilot be an area expert but also that refinement of the pilotage model to accommodate area-specific operational and environmental factors be developed and administered by individuals knowledgeable of them. For practical purposes, this task requires the participation of individuals from the area served. Local participation is also desirable in order to build pilotage system credibility with the local public.

Audits

Pilotage is in most cases a government-sanctioned, limited-entry business designed to maintain marine pilots in numbers that are in balance with time-consuming professional-development requirements and at compensation levels appropriate to the service provided. Because of its relatively closed nature, pilotage draws considerable controversy over the efficacy of pilot recruitment, performance, administration, and rates. To establish the efficacy and credibility of the pilotage system, a complete pilotage model would provide for independent audits of system features to ensure that integrity, effectiveness, and efficiency are maintained.

Standards

Administrative Standards

The administrative support of pilotage systems needs to be as credible as pilot services themselves to maintain the integrity and credibility of the entire system. To sustain its credibility, the pilotage model would include provisions for standard procedures, administration, billing, logistic support, disciplinary proceedings, financial accountability, record keeping of safety data, and other information.

Professional Standards

The true meaning of professional standards in piloting is difficult to quantify; most standards are very subjective and highly variable among pilot areas and systems. Where standards involve numbers, they usually refer to round trips, years of service, and so forth. Generic and port-specific standards that could be used to gauge professional performance are not available. A complete pilotage model would include standards to guide professional development and performance. In the absence of fundamental research to guide development of standards, such standards would need to be developed by subject matter experts. However, to aid in the acceptance of standards by all interested parties, the standards could be developed by a multidisciplinary team representing the view-points and expertise of the interested and affected parties.

Physical Condition Standards

Piloting demands excellent physical conditioning, to assure that the pilot not only is physically able to provide service but also can board and debark the vessel to which assigned. Physical standards need to be established by pilotage authorities. Each pilot should have a periodic physical examination to determine suitability for continuing work. In determining physical standards, pilotage authorities could consider the physical-examination guide developed in 1985 by the Seafarers Health Improvement Program Committee for merchant seamen. While there are no national physical standards for marine pilots, this program is available for use by pilotage authorities. Physical suitability should be determined prior to granting an initial license, at the time of license renewal, or more frequently if licenses are renewed at intervals of more than two years. Also needed are provisions for physical examinations following a serious injury or illness, along with provisions for examinations if evidence shows that the physical condition of a pilot has deteriorated.

Organization

Organizational Structure

Pilotage associations and boards (or commissions) need to be organized for sound decision-making and administration. Various organizational structures have been used for pilot organizations—some are organized as professional as sociations for administration; some are corporations; some are companies with pilots as stockholders or employees; and in a few cases, some are divisions of government organizations. All forms are in existence and functioning, nationally and internationally. Each form at one time or another has also experienced failure in maintaining the efficiency of pilotage services. No one form stands out as a perfect model. Whatever form is chosen needs to be responsive to both safety and economic need within the overall system.

Pilot boards generally consist of appointed or elected members who serve for a set term. Membership composition varies greatly, from all pilots to no pilots. Sometimes shipping interests and the public are represented and sometimes not. Because multiple interests need to be served, each viewpoint must be represented in decision-making and administration. This balance can be facilitated by including marine pilots and shipping, port authority, public safety, and public interests in board membership. Whatever composition is chosen must be responsive to the broad range of marine safety interests for the waters served, including operational, economic, and environmental protection factors.

The economic factor of pilotage rates has indirect implications for safety. How rates should be administered and by whom, and what rates are reasonable, are very controversial issues to which the pilotage model needs to be sensitive. Rates established by law are inflexible to changing conditions, require legislatures to act, and immediately inject rate negotiations into the political process. On the other hand, legislative oversight of rates and rate-setting procedures provides protection from various anti-trust laws that might otherwise be imposed for closed-access businesses. Regulatory rate-setting provides somewhat more flexibility in addressing changes in economic conditions, but it may require considerable processing time if public hearings are involved. Hearing processes can take on the aura of litigation, and hearings may or may not be heard by an officer or judge competent in marine affairs.

Rates set by pilotage boards place these boards in the position of having to make tradeoffs between economics and safety, and between the interests of shipping companies and the pilots under their jurisdiction. Negotiated rates may or may not provide for adequate pilot compensation, depending on the economic power of the shipping companies relative to the ports to which they can call. Whatever rate-setting structure is chosen needs to ensure adequate compensation for the expert service that is provided, sufficient resources to maintain an adequate pilot pool, and infrastructure requirements for effective and efficient service. Rate setting as a function separate from pilotage administration merits consideration in pilotage systems.

Infrastructure

Pilotage services need to be available on a 24-hour basis in most pilot service areas and under virtually all environmental conditions. To provide universal service, pilot vessels, dispatch services, administrative offices, and other support are needed. Infrastructure needs vary greatly by operating environment. In some cases such as open sea approaches to pilot grounds subject to heavy weather, all-weather station boats are essential. In other cases, where headlands or other features may offer protection, pilot launches may suffice. In inner harbors, smaller launches or transport via tugboat may be sufficient. Dispatch services may or may not need to include a pilot tower at harbor entrances or in the harbor itself. Tower equipment may range from radios and telephones to radar and vessel traffic service equipment. One or more dispatch offices or stations may be needed. All these elements need to be accommodated in the pilotage system.

Appendix F

Pilot Training Requirements

Following is a summary of training requirements for selected pilotage jurisdictions in the United States, Canada, the Netherlands, the United Kingdom, Sweden, and the Panama Canal. The emphasis is on requirements for an original pilot's license (as opposed to renewals or certificates of exemption) and, when noteworthy, continuing education. This listing is not exhaustive; rather, examples were selected to illustrate the considerable diversity in training requirements, both within the United States and worldwide. A summary of training in the towing industry is also included, as pilotage in the industry under existing rules and regulations relies heavily on vessel operator experience.

The sources for this appendix include written and oral presentations to the committee, statutes, rules and regulations, and other documents provided by pilot organizations and individual experts.

Federal Pilot Licenses and Endorsements

General requirements for pilot certification and licensing are set by statute. Applicants must demonstrate "the requisite general knowledge and skill" and proficient use of aids to navigation, and they must have "sufficient experience … to evidence ability to handle any vessel of the type and size which the applicant may be authorized to pilot" (U.S.C. Annotated, 1990, Section 7101).

Specific minimum requirements are contained in the Code of Federal Regulations Title 46 and local Coast Guard policies as determined by the Officer in Charge of Marine Inspection (OCMI). An applicant for a Federal First Class Pilot's License (general routes) must have 36 months' service in the deck department of steam or motor vessels, including 18 months as quartermaster; wheels man; able seaman; apprentice pilot; or in an equivalent capacity, standing regular watches at the wheel or in the pilothouse as part of routine duties. At least 12 of the 18 months must be on vessels operating on the class of waters for which the pilot license is sought (CFR 46:10.703).

To qualify for an original license, an applicant must complete 12 to 20 round trips, 25 percent of them during darkness, while serving as quartermaster, wheelsman, able seaman, apprentice pilot, or in an equivalent capacity, *or* as an observer. One of the round trips must be made in the 6 months immediately preceding the date of application. Additional trips may be required by the OCMI for an individual to qualify for a particular route in order to become familiar with the geographic configuration of the waterway, the type and size of vessels on the waterway, the availability of aids to navigation, background lighting, and known hazards (CFR 46:10.705).

A candidate must pass a written examination covering piloting, celestial phenomena, seamanship, watchkeeping, compasses, meteorology, shiphandling, pollution prevention regulations, shipboard management and training, and communications. The candidate must also make a chart sketch of the route, detailing recommended courses, distances, prominent aids to navigation, depths of waters in channels and over hazardous shoals, and other important features of the route, such as character of the bottom (CFR 46:10.707, 10.901, 10.910).

Once licensed, a pilot must meet one continuing-education requirement: one re-familiarization round trip every 60 months (CFR 46:10.713). There are no specific pilot training or skill requirements, or skill development requirements beyond experience and trips, although federal pilot associations providing local or regional services may adopt additional requirements.

Interport Pilots Agency (Connecticut, Delaware, New Jersey, New York)

Interport selects pilot candidates with extensive maritime experience and a federal pilot's license. To earn a federal license in the Port of New York and New Jersey, a candidate must complete at least 36 round trips and pass a series of examinations, the first for the original license and an additional test for each route endorsement. The candidate then is required by the association to ride and train with experienced pilots. The candidate begins piloting alone upon approval of the association membership, working jobs of increasing difficulty while gaining experience and confidence. There is no set time period for training, but it generally lasts 1 to 2 years (Lou Bettinelli, Interport Pilots Agency, personal communications, May 29–31, 1991).

New York/New Jersey Docking Masters

State regulations specify that a docking master must have a federal pilot's license and at least 10 years' experience working in vessel deck departments, including 5 years as a licensed master or mate. Six years of training are required. Within the first 2 years, the trainee must observe at least 225 passages, dockings, and undockings; at least 25 of these maneuvers must be performed by the trainee under the supervision of a docking master. During the next 4 years, the trainee is to be given assignments of increasing difficulty commensurate with experience (New York State Regulations, Part 57, provided to the committee by the Board of Commissioners of Pilots of the State of New York, May 8, 1991). A trainee rides with and observes senior pilots for at least one year before being assigned to the first solo job. The time period varies according to evaluations of the trainee by senior pilots and the Operations Department of McAllister Towing & Transportation Co., whose clients the docking masters serve. The trainee then is assigned light work until it is determined, through regular evaluations, that work difficulty can be upgraded. During this period and throughout their careers, pilots are expected to ride with and observe senior pilots (Robert A. Moore, New York/New Jersey Docking Masters, personal communication, May 29, 1991).

McCormick Docking Pilots (Port of New York and New Jersey)

Docking master candidates must have experience as tug mates or captains. Potential candidates initially accompany senior tug captains to learn shiphandling, local knowledge, and low-speed maneuvering. After evaluation by the tug captain and the tug operations division, candidates become relieving captains on smaller tugs. If they show aptitude for piloting, then they may be assigned either as a mate with a tug captain/docking pilot, or as a captain of a ship-docking tug. Throughout this period, the candidate is observed by seasoned senior docking pilots or tug captains. The hands-on apprenticeship lasts at least 10 years, including at least 5 years as a licensed mate or captain. During these 5 years, the candidate must observe on the bridge of an oceangoing vessel with a senior docking pilot on at least 225 passages, dockings, or undockings; the candidate also must perform at least 25 maneuvers within a 2-year period. Upon completing the apprenticeship, a pilot is scrutinized and evaluated carefully during the progression to senior pilot status, a process than can take 10 years (Richard P. Wieners, McCormick Pilot Association, personal communication, July 29, 1991).

Wilmington-Cape Fear Pilots (North Carolina)

Under the state code, the Cape Fear Navigation and Pilotage Commission establishes rules and regulations regarding pilot qualifications. The commission has adopted a Coast Guard-approved apprentice training program developed specifically for the Wilmington-Cape Fear Pilots Association. Applicants must have a 4-year college degree or a minimum third mate's license (unlimited ocean) and must be recommended by a majority vote of the association and approved by a majority vote of the commission. The apprenticeship lasts up to 3 years for unlicensed applicants, up to 1 year for third mates. During the apprenticeship, novices must make at least 360 trips and third mates at least 120 trips. The apprentice is tutored by licensed pilots and must master learning tasks that meet the job performance needs of piloting, which were determined by a formal job task analysis (Bennett, 1989). A candidate's progress is graded every 6 months by tutor pilots, and a detailed log is kept of each trip under the guidance of tutor pilots. (Basil R. Watts, Wilmington-Cape Fear Pilots Association, personal communication, December 16, 1991). Following the apprenticeship, a candidate recommended by a majority of the association may be issued a limited license. During the next year, the pilot serves on ships of increasing draft and tonnage, with each increase endorsed by a majority of the association. At the end of the year, upon recommendation of a majority of the association, the commission may issue a full license (Bennett, 1989).

Cape Fear Docking Pilots (North Carolina)

Cape Fear docking pilots have extensive experience on tugs, having served in all capacities from deckhand to captain and even in engineering roles. A pilot candidate initially rides as an observer to the senior docking pilot on vessels of the size and character that the trainee later will handle. Although there is no formal apprenticeship program, docking pilots are brought up "through the ranks." As a deckhand, a candidate is observed by the tug captain, and promotion is based on merit. Once promoted to relief captain or mate, the candidate gains experience in shiphandling and learns how ships and tugs interact. Having advanced to mate or captain and obtained a federal pilot's license, the apprentice continues to ride as an observer with senior pilots. After a sufficient number of observation trips, the candidate pilots vessels of limited draft and tonnage with supervision. There is no specific trip requirement. The candidate is evaluated by senior pilots and is allowed to progress at an individual pace (James A. Register, Cape Fear Docking Pilots, personal communication, July 8, 1991).

Associated Federal Coast Pilots (Louisiana)

The Associated Federal Coast Pilots require pilot candidates to have a federal pilot's license and at least 5 years' experience as a deep-sea master or harbor tug master (with some exceptions). Prospective candidates are screened on eight parameters. After a vote by association members, the top two candidates are screened more thoroughly. Members then vote again to select one candidate as an apprentice. The 6-month apprenticeship begins with 1 month of rides with pilots as an observer, followed by hands-on training under pilot supervision (Fred Boyd, Associated Federal Coast Pilots of Louisiana, personal communica tion, January 15, 1992). The Coast Guard requires 20 round trips (Associated Federal Coast Pilots, correspondence, September 23, 1991). Then there is a probationary period of 1 year—longer if necessary—with a vessel draft restriction of 25 feet, followed by another vote. Apprentices are graded during their probation on ability, shiphandling, pilot/captain working and interpersonal relationships, Coast Guard-required knowledge, and knowledge of the river. The association sends some members for shiphandling simulation training (Fred Boyd, as noted above).

Puget Sound (Washington)

Under local Coast Guard policy for Puget Sound, candidates for an original federal pilot's license or endorsement must complete 12 round trips as master, 15 round trips as mate or observer, or 18 round trips as able seaman, quartermaster, or wheelsman. Certain routes require fewer round trips. For example, 3 to 9 round trips are required for certain main channel routes, 9 to 12 round trips for terminal ports (after approval for the adjacent main-channel route), and 3 round trips for an interconnecting ferry route. Candidates also must pass the standard examination, including the chart sketch (Coast Guard, Marine Safety Office Puget Sound, Form 009, March 1989).

State Pilot Licenses

Training requirements for state-licensed pilots may be established by state statute or regulations, or both, or by pilot associations. Programs range from highly prescriptive to informal; all involve on-the-job training that relies on the judgment of supervising pilots. Some jurisdictions accept pilot candidates with little or no maritime experience, while others require prior sea service, often designating experienced trainees as deputy pilots. Virtually all state-licensed pilots also obtain a Federal First Class Pilot's License, either as a condition of employment or as a required step in the training process. In any case, state-licensed pilots have a financial incentive to obtain the federal license, because it enables them to serve ships in the domestic trade.

Alaska

Under the Marine Pilotage Act that took effect in 1991, a state Board of Marine Pilots establishes criteria for selecting pilot trainees and for training programs conducted by pilot organizations. An applicant for deputy pilot must have significant maritime experience, including 2 years' service as a licensed master on vessels or tug and tow of at least 1,600 gross tons, 2 years' service as a commanding officer of U.S.-commissioned vessels of at least 1,600 gross tons, and 3 years' experience as a member of a professional pilot's organization while an active pilot. Candidates must also pass written and oral examinations and complete training requirements established by the board. The law specifies that required training may include supervised trips, dockings, undockings, and tug-assisted maneuvers; any special training necessary for a particular pilotage region; and completion of the training program within a specified time period. After three years as a deputy, a candidate is eligible for a marine pilot license (House Bill 194 [L&C], 17th Legislature, First Session, Legislature of the State of Alaska, May 19, 1991).

California

San Francisco Bar Pilots

A pilot training program and training standards for pilots, inland pilots, and pilot trainees are required by California's Harbor and Navigation Code, Section 1171.5. The code provides basic specifications for training and charges the California State Board of Pilot Commissioners for the Bays of San Francisco, San Pablo, and Suisan to develop specific standards and programs. The standards are required by law to equal or exceed standards for federal pilotage. The code specifies a minimum of 1 year and a maximum of 3 years training for pilot trainees. Also required is a pilot evaluation committee consisting of five active licensed bar pilots. The State Board is responsible for selecting and examining pilot trainees. The board also selects members of the pilot evaluation committee who are responsible for conducting and supervising the training programs.

Regulations specify that candidates must hold a valid federal master's license with an unlimited radar observers' endorsement. Under the board's licensing standards, pilot candidates must also have served at least 2 years as master or pilot in another area. Trainees are selected by the board based on oral and written examinations. They must complete 1 to 3 years of on-the-job training under the supervision of a licensed bar pilot, who must submit written reports that are required by the pilot evaluation committee. During this period, trainees must obtain all applicable endorsements for federal pilot licenses and attend various simulation training courses specified by the committee, which evaluates trainees throughout the training period and reports regularly to the board. The Coast Guard requires a minimum of 15 round trips through each of seven pilotage areas to qualify for examination for federal endorsements covering all pilotage waters in the area; the number of additional trips is not specified. Generally, a trainee with substantial sea service and piloting experience makes about 200 additional round trips. A trainee with lesser marine experience typically makes up to an additional 500 or more trips (Arthur J. Thomas, San Francisco Bar Pilots, personal communication, August 5, 1991).

The State Board reports that the training curriculum consists of trips on all sizes and classes of vessels on all pilotage routes and into all berths on those routes. It also consists of classroom instruction covering all aspects of a pilot's duties supplemented by computer-based and manned-model simulations. Under a continuing professional development program, all licensed pilots are sent to a one-week course in manned-model shiphandling simulation (Charles Adams, California State Board of Pilot Commissioners, personal communication, July 16, 1991). This requirement for active pilots is being expanded to require attendance at computer-based shiphandling simulations for training in bridge team management and emergency procedures. The board reports that the curriculum, although not previously published, has been consistently applied to all trainees and is scheduled for publication.

Long Beach and Los Angeles

Long Beach and Los Angeles pilots hold federal licenses only, even though they serve ships in foreign trade. State licenses have not been required (see Chapter 3).

The Port of Long Beach appoints a Board of Pilot Commissioners, which contracts for pilotage service. The contractor is Jacobsen's Pilot Service, a private, employee-owned company that trains and employs pilots. Pilot candidates are screened for background, experience, and personality; about 80 percent of Jacobsen pilots come from the towing industry. The performance-based training program takes at least two-and-a-half years, including a 1-year probationary period. An apprentice is assigned about 70 to 80 jobs per month, with training directed at filling any gaps in prior experience. Former ship officers ride tugs, for example, and candidates from the towing industry ride ships. Trainees are also introduced to the business side of shipping, to build appreciation for the whole system. Computer-based shiphandling simulation is used for practicing risky maneuvers and for training in communications. Apprentices are evaluated by experienced pilots in consultation with experienced ship masters (John Strong, Jacobsen's Pilot Service, personal communications, October 6–8, 1991.)

In Los Angeles, pilotage is regulated by the Board of Harbor Commissioners, which is appointed by the mayor and empowered by the state to establish pilotage regulations for foreign trade. Local pilots are civil servant employees of the commission. Under city rules, pilot candidates must have 3 years of full-time paid experience as one of the following: licensed master or chief mate of an inspected vessel of at least 5,000 gross tons on any ocean; port pilot whose duties include docking and undocking of oceangoing or coastwise vessels in a major U.S. port; or master of a tugboat in San Pedro Bay and its tributaries, with experience as docking master on flat tow vessels of at least 5,000 gross tons. In keeping with the city's standing but unwritten practice, candidates take an oral examination, and the top six scorers are interviewed in-depth. Candidates are interviewed to assess their training, experience, and personal qualifications; of particular interest is ability to pilot and navigate all types of oceangoing vessels and to deal tactfully and effectively with ships' agents and officers. The pilots have established, informally but with the approval of the port's director of operations, a 2-year training program. At the beginning of training, trainees ride as observers with pilots and aboard tugs. After 3 or 4 weeks, they begin to pilot vessels of limited size in and out of anchor; size limitations are increased gradually, at a rate that depends on the trainee's progress and prior experience (Ward Pearce Jr., Worldport Los Angeles, personal communication, July 8, 1991; Patrick Donohugh, assistant chief pilot, personal communication, April 21, 1993).

Florida

Under state law, candidates for deputy pilot must have 2 years of sea service in the last 5 years to be eligible for the initial certification examination. Passing candidates are issued a 9-month temporary deputy certificate for a designated port. The state Board of Pilot Commissioners evaluates the deputy's performance for suitability to continue training and makes a recommendation to the state Department of Professional Regulation. Given a favorable recommendation, the deputy receives a 2-year certificate, which may be renewed as necessary. To obtain a full pilot license, a deputy must obtain a federal pilot's license, complete the board-approved training program developed by the local pilot's association, and pass an additional exam. The law sets parameters for training: the deputy must serve at least 90 days as an observer trainee and must submit to the board a written report for each trip accompanying a state pilot. The deputy gains experience in stages, serving vessels of increasing length and draft, with each request for an increase submitted to the board. Active pilots must attend a board-approved seminar for continuing education (Florida Statutes, Chapter 310.071-.081).

Port Everglades

The deputy pilot training program includes at least 600 rides with senior pilots over a period of at least 3 months (Robert I. Jackson, Port Everglades Pilots' Association, personal communication, July 18, 1991). Association rules require each active pilot to participate in simulator training every 5 years (Edward "Ned" Cray, Board of Pilot Commissioners, State Pilotage Symposium, Fort Lauderdale, Florida, September 20, 1991).

Tampa Bay

The deputy pilot training program consists of nine levels defined by gradually increasing vessel-size limits. Level 1 is the observer trainee stage, during which a candidate obtains a federal pilot's license and then may pilot vessels under supervision. At Level 2, the candidate may pilot vessels with a draft limi tation of 21 feet and length limit of 500 feet. By Level 9, the draft limit is increased to 37 feet. Candidates must train for at least 90 days at each level and must obtain the recommendation of all tutor pilots to complete that level. Before requesting board approval to advance, a deputy must handle at least two vessels of the next level under the supervision of a state-licensed pilot and must receive that pilot's recommendation (Department of Professional Regulation, Deputy Pilot Training Program, Approved by the Board of Pilot Commissioners, January 26, 1988 [Revised May 16, 1990]).

Hawaii

Under state administrative rules, an applicant for deputy pilot must have an unlimited master's license, federal pilot endorsements for all Hawaiian ports, 4 years' experience as a licensed deck officer including one as chief officer (or 2 years as an officer and 1 as a pilot), and at least 50 round trips in and out of Honolulu Harbor as an observer. The applicant also must pass a written examination. Before applying for a full port pilot license, a deputy must serve at least 18 months, including 6 months piloting vessels under 500 feet in length and less than 30 feet in draft. A deputy must have 12 months' experience before piloting a tanker or passenger vessel. The director of commerce and consumer affairs may contract with a "qualified entity" to establish a training program (Hawaii Administrative Rules, Title 16, Chapter 96, Subchapter 6).

The Hawaii Pilots Association's 2-year training program requires that, in addition to the 50 round trip entry requirement, trainees complete 350 observation trips in Honolulu with a licensed pilot and 500 solo assignments. Most trainees make even more transits (Leonard A. Stenback, Hawaii Pilots Association, personal communication, July 16, 1991).

Because pilotage varies from port to port, the training program of the Port Pilots of Hawaii is designed to provide a deputy with maximum shiphandling training in Honolulu Harbor, after which the learned skills can be applied under the supervision of a licensed pilot to other routes. Each deputy pilot acquires local knowledge in an individual manner. The state Department of Commerce and Consumer Affairs is studying proposals for the continuing training of pilots (Lou Geronimo, Port Pilots of Hawaii, personal communication, November 18, 1991).

Louisiana

About 20 percent of all state-licensed pilots in the nation work on the Mississippi River. Three pilot associations operate on the river (Michael R. Delesdernier, personal communication, January 17, 1992). Under state law, the pilots in each association are regulated by a board of commissioners or examiners, which set minimum standards for applicants. Applicants must have a federal pilot's license and serve a 6-month apprenticeship (Louisiana Senate Bill 956, Act 418, Regular Session of 1988, Section 1, R.S. 1045). The pilot associations establish local training programs to meet the governing board's standards.

Crescent River Port Pilots

Pilot candidates in the Crescent River Port undergo a 12-month apprenticeship and 1 year of limited service (Michael R. Delesdernier, as cited above). A federal pilot's license for any gross tons is a prerequisite. The apprenticeship includes a seminar, sessions on maritime law and customs, discussions by shipping agents, reviews of past incidents, and shiphandling courses. Candidates may be enrolled in manned-model shiphandling simulation courses. Once all qualifications are met, candidates can be issued a state license under the oversight of the Board of Examiners (Mark Delesdernier Jr., Crescent River Port Pilots Association, personal communication, January 15, 1991).

New Orleans-Baton Rouge Pilots

The New Orleans-Baton Rouge Steamship Pilots Association (NOBRA) requires candidates to have a federal pilot's license, a high school diploma or two years' service in the wheelhouse, and a river master's or mate's license. In general, applicants have 8 to 10 years experience as pilots. The association "orients" pilots for about 6 months rather than training them. Candidates then take the board exam, which focuses on practical piloting rather than theory. Newly licensed pilots are restricted to vessels of less than 40,000 gross tons and 36-foot draft (C. E. "Joe" Clayton, NOBRA, personal communication, January 15, 1991).

Associated Branch Pilots

Pilot candidates are required to have 2 years of sea service. (One year of the Coast Guard's 3-year requirement was waived in consideration of the association's informal apprentice training program, which lasts at least 2 years.) The candidate begins training as a boatman, observing senior apprentices for a month or two. The candidate then maintains and operates pilot boats for about a year, thereby learning the local routes. The pilots then judge whether the candidate is ready to become an apprentice pilot. During the apprenticeship—which normally lasts 2 to 3 years—the candidate first rides as an observer when not on watch. The pilots then begin to tutor the apprentice, who gradually assumes piloting duties under supervision. Each apprentice progresses at an individual pace. The federal's pilot license is obtained during this period. When ready, the apprentice begins "cubbing"; state regulations specify that a cub must pilot (under supervision) at least 650 trips total over the three local routes during a 9-month period. The cub then is tested by the Board of Examiners, who may recommend a pass ing candidate to the governor for appointment as a pilot (Jacques Michel, personal communication, April 21, 1993).

New York

The Port of New York and New Jersey is served by two pilot associations that operate jointly as the United New York and New Jersey Sandy Hook Pilots' Association. New York State regulations specify the educational and training requirements for pilot candidates, who are selected by the state Board of Commissioners for Pilots. Candidates must have 2 years of college, including at least 56 credits in subjects approved by the board. The board selects Sandy Hook apprentices based on academic record, satisfactory completion of prescribed courses at the Sandy Hook pilot school (or the equivalent), and personal interviews. Regulations call for a candidate to spend at least 2 years as a junior apprentice before promotion to boat-keeper. Beginning in the 16th month as boat-keeper, the candidate must be instructed in shiphandling and all aspects of piloting. An apprentice must complete at least 225 passages in the company of licensed Sandy Hook pilots. The apprentice must also pass an examination (New York State Regulations, Part 51, Pilot Apprentices and Pilots in Training, provided to the committee by Robert H. Pouch, Board of Commissioners of Pilots of the State of the New York, May 29, 1991).

The pilots' association maintains a full-time pilot instructor at the Sandy Hook pilot school on Staten Island. The initial apprenticeship lasts three-and-one-half years, after which the candidate becomes a registered apprentice for four years. The training program includes 6 days per month of academic classes in nautical science and assignments to be completed while on sea duty. Apprentices also gain practical shiphandling experience, riding about 400 ships during the first six-and-three-quarter years. Before piloting ships alone, a senior registered apprentice undergoes an intensive 9-month training, piloting an additional 225 ships under the supervision of senior pilots. Additional specialized training is given outside the school in fire fighting, radar, and automatic radar plotting aid (ARPA). Each apprentice is evaluated once a month by the director of training. After completing the apprenticeship, the trainee undergoes up to 1 week of written and oral examinations before becoming a deputy pilot for vessels limited to a 24-foot draft and 10,000 tons. These limits are increased on a schedule that is based on performance reviews, and all restrictions are removed after 7 years of satisfactory service. The total period of training and experience lasts at least fourteen-and-one-half years. (Vincent A. Black, United Sandy Hook Pilots of New York and New Jersey, personal communications, May 29–31, 1991).

Maine

Maine law requires that pilot applicants have a federal pilot's endorsement and access to proper means for boarding and leaving vessels (Maine Public Law, Chapter 509, Title 38, August 1991).

Portland Pilots, a small association for the port of Portland, does not require candidates to have a master's license for oceangoing vessels, but most recruits have served in that capacity. Association members initially judge a candidate's ability based on their knowledge of the candidate and employer recommendations. During training trips, the pilots assess the candidate's natural ability, adaptability to sudden events, demeanor on the bridge, and rapport with ships' crews. There is no specific trip requirement. Initiative, common sense, ability, and willingness to accept the responsibility of prudent piloting are paramount (Granville I. Smith, Portland Pilots Inc., personal communication, July 12, 1991).

Maryland

Under guidelines in the state code, the Maryland State Board of Pilot Commissioners interviews applicants and selects those qualified to become apprentices. Pilot candidates must have graduated from a 4-year course at an accredited maritime institution and possess a license as third mate or greater grade of steam and motor vessels of any gross tons upon oceans, or must possess a valid license as master of steam and motor vessels, any gross tons upon oceans. The code states that the most qualified individuals will be chosen (Annotated Code of Maryland, Business Occupations and Professions Article, Title 11: Code of Maryland Regulations 09.26). Apprentices must spend at least 2 years riding as an observer aboard all sizes and types of vessels, under the tutelage of senior pilots. Apprentices are allowed hands-on experience aboard hundreds of different vessels; more than 200 trips are made. During the apprenticeship, candidates must pass Coast Guard examinations for each route; their progress is reported to the state commissioners. As a final review, pilot members of the board observe each candidate's onboard performance and report their findings to the full board. Each candidate then takes a written examination covering local knowledge, hydrodynamics, ship interaction in narrow channels, and other areas of knowledge relevant to shiphandling and piloting (Richard. W. Owen, Association of Maryland Pilots, personal communication, August 28, 1991).

Oregon

State law requires that candidates for river pilotage have 6 months' continuous experience piloting oceangoing vessels over the pilotage ground. Also required is essential experience in maneuvering oceangoing vessels through the bridges through a range of operating conditions. The law also requires that candidates satisfy any requirements, including examinations, adopted by the Oregon Board of Maritime Pilots. The board has adopted additional requirements, which vary by pilotage ground (Kevin Q. Davis of Stoel, Rives, Boley, Jones & Gray, personal communication, October 6, 1991).

Columbia River Bar Pilots

A candidate for Columbia River Bar pilot must have 2 years' experience as master of an offshore merchant vessel and must make a minimum of 100 crossings of the bar, 25 percent during darkness, under the supervision of a state-licensed pilot (Kevin Q. Davis, as cited above).

Columbia River Pilots

A candidate for Columbia River pilot must have at least 2 years' experience as captain of a towing vessel on the Columbia and Willamette rivers. Candidates generally have 12 to 25 years of prior experience (Jack Vonfeld, Columbia River Pilots, personal communications, October 6–8, 1991). Training is accomplished on-the-job; trainees serve a 2-year apprenticeship during which senior pilots certify progress by signing a trip sheet (Glen Hurn, Columbia River Pilots, personal communication, July 12, 1991). River pilots pass through three pilotage grades over a period of at least 18 months, gaining experience with vessels of increasing size, before receiving unlimited licenses (Kevin Q. Davis, as cited above).

South Carolina

Active pilots select applicants, subject to approval by the Commissioners of Pilotage, based on a numerical ranking system outlined in the commissioners' regulations. The regulations require 3 years of training, including an apprentice training course with a specified curriculum. An apprentice must complete 360 round trips involving at least 360 days aboard vessels over 1,600 gross tons. The apprentice is graded every 6 months by tutor pilots on procedures, skill, communications, and attitude; the apprentice must receive a minimum grade of 3.2 on a 4.0 scale from a majority of tutors. (Final Regulation, Commissioners of Pilotage, Port of Charleston, Chapter 136.) The Coast Guard-approved course involves observational mastery learning, a form of on-the-job training. The apprentice and the tutor pilot interact through coaching and queuing until the apprentice can replicate the learned material without assistance. Apprentices must pilot solo to the satisfaction of the tutor under all conditions and on every vessel size. Apprentices typically complete 1,300 to 1,400 trips (Whitemarsh S. Smith III,, Charleston Branch Pilots Association, personal communication, July 9, 1991.)

Texas

A review committee of the Houston Pilots association interviews, evaluates, and recommends pilot applicants to the full membership. The association then nominates deputy pilots, who must be approved by the Board of Pilot Commissioners for the Port of Houston Authority. Deputy pilots undergo a two-year training program, riding with all pilots on various vessels for 2 to 6 months, until the supervising master and the association membership determine that the deputy can pilot alone. Deputy pilots pass through three grades, piloting ships of increasing size and weight. In their last 6 months of training, under the direct supervision of the master and other pilots, they must ride and handle vessels over 24,000 gross tons and car carriers. Deputies must handle at least three such vessels during periods when they would otherwise not be in a duty status. The supervising master and association pilots are the sole judges of whether a deputy is qualified to become a full pilot (Harry Lydick Jr. and Armando Luna Jr., Houston Pilots, personal communication, September 12, 1991).

Washington

State licensing regulations for pilots require 75 to 100 training assignments on various routes, depending on the background and experience of the individual candidate (William A. Bock, Puget Sound Pilots, personal communication, July 17, 1991). Pilot trainees in Puget Sound must obtain federal pilotage endorsements, pass the state's written and oral examinations, and complete 100 training trips developed by the Board of Pilotage Commissioners. The trips must be completed during a 6-month period under the supervision of a pilot with at least 5 years' experience. State law stipulates that the board *may* require simulator training for pilot applicants and *will* require such training in the first year of active duty and at least once every 5 years for all active pilots. State law also requires that vessel sizes and types be limited during the first 5 years of a pilot's active duty (William A. Bock, Puget Sound Pilots, personal communication, October 7, 1991).

British Columbia, Canada

Pilotage is under federal jurisdiction in British Columbia, Canada. Pilot applicants must have served (1) as a master for at least 735 days, (2) as a watch-keeping deck officer for at least 490 days and as master for at least 365 days, or (3) as a deck watch officer for at least 1,000 days who has completed at least 20 familiarization trips (Pilotage Act, Chapter 1270, Pacific Pilotage Regulations, 1978). The Pacific Pilotage Administration (PPA), which oversees pilotage in the region, contracts with British Columbia Coast Pilots. Pilot candidates are examined by a committee appointed by the PPA. Successful candidates serve an apprenticeship of at least 6 months and must attend a course in manned-model shiphandling simulation. Under a contractual agreement between the pilot association and the PPA, newly licensed pilots are limited as to the size and type of vessels they may serve; these limits are increased annually for 5 years, after which the limitations are removed. The pilot association, in conjunction with PPA, enrolls pilots in special training courses considered mutually desirable; all pilots have taken a 3-day ARPA course (Wayne Whyte, British Columbia Coast Pilots Ltd., personal communications, October 6–8, 1991).

The Netherlands

Formerly government employees, pilots were "privatized" in 1988. The training and examination procedures are derived, with minor alterations, from the rules and regulations for the old government system. A pilot applicant must be a licensed master for unlimited foreign voyages and must be an apprentice in one of the four regional pilots corporations. An apprentice takes a 2-month national training course, followed by an exam. The training includes classes taught by senior pilots and nautical academy lecturers, as well as practical shiphandling instruction. The trainee then receives 10 months of regional shipboard training with experienced pilots, followed by another exam and test voyages. A total of 210 training trips are required, 30 to 70 for each pilotage area. Trainees also visit vessel traffic service stations, pilot boats, and companies associated with the port. No simulators are used in the training or examinations; simulators are used only by experienced pilots (Herberger et al., 1991).

United Kingdom

Under the Pilotage Act of 1987, pilotage for each harbor is regulated by a harbor authority, which "authorizes" and employs pilots judged to be qualified after training and evaluation. The Port of London Authority (PLA) has jurisdiction over London, the largest U.K. port. PLA trainee pilots must have a master mariner's certificate and must have served as a master or first mate. During 6 months of initial training, they make an average of 210 to 220 trips with an authorized pilot, plus 20 trips on tugs. Trainees then must pass oral examinations covering pilotage areas, PLA bylaws, general directions for navigation, bylaws on dangerous substances in bulk, and PLA Notices to Mariners. Initial authorization is for ships of limited draft and length; these limits are increased gradually and are eliminated after a minimum of 360 trips and 28 months (Herberger et al., 1991, Tab I, "Memorandum from the Pilotage Manager, July 25, 1991").

Sweden

Swedish pilots are government employees, selected and trained by regional pilot boards composed of pilots and government administrators. A pilot appli cant must have a master's license and must undergo interviews and a 6-month training period, including trips with pilots. Candidates may pilot very small ships after as little as 2 months of training. Their progress is certified by pilots. Advancement to full pilot status takes 4 years (Herberger et al., 1991).

Panama Canal

Panama Canal Company pilots are federal government employees, although this status is in transition under the terms of the Panama Canal Treaty. Pilot development requirements were established following the federal pilotage program for structure and for licensing requirements. In addition, there is a formal, structured apprenticeship and progressive advancement program (once licensed) similar in concept and structure to that employed by the Sandy Hook Pilots. At one time, an unlimited master's license was required, although a master's license for bays, lakes, and sounds is now the entry-level threshold for a license issued by the Panama Canal Company. Check rides overseen by qualified pilot examiners are required as part of initial licensing and for upgrading during progressive advancement for the first 2 years. The check rides in the past were qualitative, however, some quantitative measures are beginning to be applied as well. Attainment of unlimited status takes about seven years. After the first 2 years, pilots, as government employees, receive written performance evaluations annually drawn from a review of available records and safety performance data. Use of field evaluations to assess pilot performance is an option if a pilot's performance becomes a concern based on safety performance (Daniel MacElrevey, personal communication, September 15, 1993; Markham, 1990; PCC, 1993).

Training In The U.S. Towing Industry

Limited information was obtained with respect to piloting training in the towing industry except for docking masters (Chapters 2 and 3). A human systems analysis for the industry comparable with that carried out in Chapter 7 for ships was not possible given the available information. Nevertheless, the following description of training in the towing industry provides a general point of comparison.

Coastal and Harbor Towing Industry Vessels

Professional development in the towing industry varies by both company and position. A wide range of training methods and topics are employed in addition to those that may be required by federal regulations. However, where training is mandated by law, it is included in the requirements for obtaining a Coast Guard license. Specifically, applicants for all original towing vessel licenses are required to complete Coast Guard-approved first aid and cardiopulmonary resuscitation courses. Fire fighting and radar observer training are re quired to obtain a license as master or mate of steam or motor vessels of not more than 500 gross tons, for ocean and near-coastal waters, and a license as an operator of uninspected towing vessels in ocean service. On-the-job training; classroom instruction; seminars; and, in some cases, simulator training may be employed (AWO, 1992b). A few technical references are available (Blank, 1989; Brady, 1967; Reid, 1986, 1992).

The most common approach is on-the-job training, although there is a growing trend toward more formalized instruction. Personnel normally work their way up from deckhand to vessel operator (the captain), building an intuitive understanding of nautical theory as it applies to towing industry operations in their area. Some individuals enter the industry upon graduation from maritime academies. In one company, graduates licensed as engineers are placed on vessels in watchstanding positions. Graduates licensed as deck officers have considerable entry-level knowledge of nautical theory, but they lack the basic tug-and-tow knowledge and skills necessary for safe and effective operations. Additional on-the-job and industry indoctrination and training is typically required (David Buchanan, Maritrans, personal communication, May 29, 1991).

Larger companies generally operate apprenticeship programs to develop their vessel operators' professional skills (Jack Hoophaugh, Hollywood Marine, personal communication, January 15, 1992; Russ Johnson, Crowley Maritime, personal communication, October 8, 1991; Steven Scalzo, Foss Maritime, personal communication, October 8, 1991). Some companies sponsor classroom training. For example, one company has a formal steersman-development program and wheelhouse school that includes classroom training designed to foster an understanding of boat handling (Foreman, 1991; Jack Hoophaugh, personal communication, January 15, 1992). Some companies operate apprentice programs, although on a semiformal basis, while others, such as smaller companies, recruit from personnel already in the industry (David Wells, Island Tug and Barge Company, personal communication, October 8, 1991). Training aboard industry vessels is normally the captain's responsibility.

A small but growing number of companies are using marine simulation to indoctrinate and train operating personnel, and a major union serving the towing industry also operates a training school with simulation capabilities. The Towing Safety Advisory Committee (TSAC) examined the use of computer-based simulation at the request of the Coast Guard in order to assist the agency in determining the feasibility and practicality of mandating such training. The advisory committee found that individuals and organizations that had experience with marine simulation considered it an effective training medium. The organization nonetheless concluded that simulation cannot take the place of actual vessel experience. Of particular relevance is the advisory committee's conclusion for the towing industry, that simulation's real value is not in teaching novices the fundamentals, but in helping experienced mariners hone their skills.

Inland Towing Industry

In the inland towing industry, boats are normally manned by a captain, "pilot," and steersman. The captain (and steersman/pilot in training) stand watch together. The second watch is the pilot. The pilot has an Operator of Uninspected Towing Vessel (OUTV) license and must be familiar with the local stretch of the river in order to get that license. If the captain has been out of the area for a while, the pilot describes what local knowledge is needed for the captain's watch.

Training focuses on developing progressive skill levels. On inland rivers, vessel operators refer to themselves as "pilots" although a federal pilot licenses are not required for this service. Nevertheless, federal pilot's licenses or endorsements can be obtained from the Coast Guard by qualified individuals (see Chapter 3). A typical progression is from steersman to pilot to relief captain to captain. In some companies, captains make the choice as to who will move into a company's steersman program. The steersman often "lives" with and follows the captain for 3 to 4 years. Operating companies prefer steersman candidates to obtain their Coast Guard OUTV license first so that the company doesn't invest in someone who is unable to get the license. Once the steersman completes training, the individual may be taken away from the sponsoring captain. The candidate may be placed aboard a "line haul" boat for a number of 30-day hitches to improve boat-handling skills. Afterward, the steersman is typically returned to the sponsoring captain's boat for piloting under that captain's supervision (Jack Hoophaugh, Hollywood Marine, personal communication, January 15, 1991; Larry Strain, American Commercial Barge Lines, personal communication, January 15, 1991).

In one company, for the first 6 to 8 months, the steersman is allowed to pilot on northbound transits only because the vessel and tow are running into the current, thereby increasing controllability. Once proficient on northbound runs, the steersman is allowed to pilot southbound. Sometimes, the pilot (the equivalent of the mate) is taken off a northbound boat at a predetermined point, and the steersman is allowed to pilot the rest of the way. A replacement pilot is placed aboard for the southbound run. Then, the steersman is placed with a second captain for a separate evaluation. This training process takes a lot of time; it takes 3 to 4 years to qualify as steersman and 3 to 5 additional years to qualify as relief captain. Again, the Coast Guard license is an entry-level requirement (Larry Strain, as cited above).

Industry representatives report that so far, marine simulation has not been developed to meet the specific needs of river towing, although such advances may be attainable in the future. Even then, simulation would be used as an aid to training rather than as the primary training medium.

Appendix G

A Primer on Navigation Technologies

This appendix provides basic descriptions of navigation technologies and serves as background material for Chapter 6. The first section outlines traditional bridge design and operation, noting the physical location of the various technologies. It provides a baseline from which to evaluate the advantages of the integrated bridge and integrated ship-control systems. The remainder of the appendix lists technologies in alphabetical order, briefly noting their important features and uses with particular reference to issues addressed in Chapter 6. Off-ship navigation technologies and essential navigation publications are included.

The descriptions are not comprehensive; there are a multitude of possible designs, uses, and combinations of many navigation technologies. These variations are due in part to the changeable marine environment. For example, radar is used for collision avoidance at sea. On approach to or while operating in pilotage waters, radar is also used to determine own ship positions.

Traditional Bridge Design and Operation

Functionally, the traditional bridge—that seen on most ships today—is laid out to support a method of operations that has not changed much since the days of sailing ships. Equipment and instrumentation are scattered about the bridge based on where the various members of the bridge team would be expected to stand during specific navigation or piloting functions. No area is equipped to support, by itself, the complete operation. Steering is controlled from the hub of the bridge based on orders from the watch officer, who may be at either side of the bridge observing radar or anywhere on the bridge or bridge wings during piloting.

The traditional navigation bridge has evolved from that of sailing ships, without much change in spatial arrangement or work functions. The bridge is located above the crew accommodations, which usually are aft on modern tankers, bulk carriers, and container ships and forward on ferries, cruise ships, warships, and most car carriers.

On sailing ships, the bridge was aft, a position dictated by the location of the rudder. Until the advent of the steering engine, rudders were controlled by tillers or an arrangement of ropes and blocks—and manpower. Thus, navigation and steering equipment had to be near the rudder. When steering engines and remote-control devices became available, the accommodations and bridge moved forward to amidships on early tankers, to provide more visibility forward of the bow. This, unfortunately, placed some accommodations directly over the cargo tanks. After many fires that led to loss of life among crews in midship houses, the International Convention for the Safety of Life at Sea (1974) and its 1978 Protocol (SOLAS) mandated that accommodations on tankers be located aft of the cargo block.

This change protected the crew from cargo fires, but the price was loss of visibility from the bridge. A large part of the sea immediately in front of the bow cannot be seen. On containerships with similar superstructure configurations, loss of visibility is increased due to the loading on deck of container boxes. This blind area forward is and likely will remain a fact of life for the mariner aboard a vessel with an after bridge. However, aft superstructures nevertheless aid in vessel maneuvering, because the response of the whole ship relative to maneuvering commands and the channel or waterway unfolds in front of the person piloting the vessel. On a forward superstructure ship, there is a loss of visibility aft. This is aggravated on ships such as car carriers, where high superstructures extend almost the full length of the ship. This is a disadvantage in pilotage waters, because the view aft is obstructed, making it more difficult to visually ascertain ship motion relative to a confined waterway and other vessels that may be approach from abaft of the beam.

Because visual navigation has been the primary means of maneuvering a ship, albeit supported by various modern navigational aids, the bridge almost always is surrounded—to the extent possible—by windows. In fact, at times essential information can be acquired or supplemented reliably only with the eyes; such information may include, for example, the presence of small craft and their maneuvers, fishing nets, tide rips, and vessel behavior relative to operating conditions (such as maneuvering behavior in shallow water). Therefore, the need for good visibility will not be diminished appreciably by the introduction of new positioning technology, even in those cases where the technology by itself effectively supports ship navigation.

In modern ships, bridge wings usually are constructed to flare from the sides of the bridge. This allows the person piloting the vessel to change positions to obtain the best view for each maneuvering evolution or to check specific aspects of an evolution, such as movement toward a pier during docking. Bridge layout and procedures also have been designed to facilitate visual navigation. For example, the steering stand usually is located on the centerline of the ship and somewhat back from the front of the bridge.

A gyroscopic (gyro) compass repeater normally is mounted above the steering stand on modern ships, although on many older ships the steering stand is configured as a binnacle, on which the gyrocompass repeater is mounted (with the gyrocompass usually located off the bridge). A magnetic compass normally is mounted in the binnacle (or in a holder mounted on or in front of the steering stand). The magnetic compass was retained to provide a means to detect malfunction and error as well as to backup the gyrocompasses before they were proven reliable (magnetic compasses still serve a general backup function).

On most ships, propulsion is controlled or ordered from a stand or console located near the steering stand. On modern ships, some form of console usually extends outboard on one or both sides of the steering stand; several groups of controls, switches, and enunciators are located on the console for managing communications, lights, engine and steering alarms, horns and whistles, and other systems the person conning the vessel might need. Radars usually are located outboard of the console and slightly forward. Most ships have two radars, one or both of which are configured as, or connected to, an Automatic Radar Plotting Aid (ARPA).

An instrument board usually is located forward of the steering stand, above the windows. This long, narrow panel contains a clock and indicators for rudder angle, engine revolutions per minute, gyroscope heading, ship speed, and depth under keel or water depth. The panel also may include displays that are useful during maneuvering, such as a rate-of-turn indicator or a docking Doppler.

Aft of the steering station is the chart room. This may be an actual room or simply an area that can be closed off at night with curtains or panels to prevent its light from flooding the steering area. The main feature of the chart room is usually a rectangular table, where the navigator can spread charts for voyage planning, plotting the ship's trackline, and so forth. There is normally a chart table on the bridge, where actual position plotting is accomplished. Navigation instruments are usually located nearby, although some may be placed in the chart room. These instruments generally include traditional equipment for celestial navigation, such as the sextant and chronometer, and some or all of the electronic navigation displays and controls. Electronic navigation refers to all techniques and systems that rely on electronic devices, including radio, radar, Loran C, and satellite navigation systems such as Transit and the Global Positioning System. [1]

[1] Electronic navigation also refers to inertial, bathymetric, and Doppler navigation, which have not attained broad use in merchant shipping. Inertial systems provide accurate dead reckoning (if they

The chart room also has numerous drawers and shelves for storage of plotting instruments, charts, almanacs, manuals, and other books and devices the navigator needs to plan and plot the ship's track and courses, and to determine its actual track and speed made good.

The walls, stands, and shelves around the periphery of the bridge usually contain other panels and instruments. These often include receivers for facsimile copies of weather forecasts and for automated notices to mariners, as well as other specialized systems. Repeaters showing information from other instruments also may be mounted in these areas, so the mariner can roam the bridge. Communications transceivers or repeaters often are placed in areas where the watch officer stands during maneuvering tasks.

The equipment used most often by pilots includes the gyrocompass, radar, Loran C, VHF radio, and various indicators (Ramaswamy and Grabowski, 1992).

Navigation Technologies: Key Features and Uses

The *anemometer* indicates the speed and direction of the wind—essential data for estimating the compass heading required to achieve a desired course, particularly when maneuvering in strong winds.

Automated docking systems/docking-assist systems comprise advanced sensor technologies (using velocity derived from lasers, microwave ranges, or Differential Global Positioning System [DGPS]) and computer technologies such as fuzzy logic or neural networks. Autonomous systems have yet to be deployed, but a number of experimental docking-assist systems are undergoing evaluation aboard operating vessels. Such systems usually include a ship-positioning system, a berthing and unberthing control system, and a communications system linked to the tugboats. Some docking systems may include a geographical representation of the ship's position, integration with the gyrocompass and steering system, and sophisticated control algorithms.

Automatic Dependent Surveillance (ADS) is a concept involving integration of data functions and the sharing of data through automatic VHF data broadcasts among Vessel Traffic Service (VTS) systems and ships in the area. The data to be shared is expected to include ship identification, course, speed, position, and possibly intent (based on the next waypoint in a voyage plan). The DGPS is the

are updated regularly using another navigation device) but would be costly for merchant use. Bathymetric navigation is an old technique that uses the topography of the ocean floor to determine position; technological advances may transform this technique into an important complement to other systems. Doppler (acoustic) navigation does not appear to have made inroads in merchant shipping.

sensor of choice for most of the information. The data could be displayed on a digital radar screen, an electronic chart system, or on a stand-alone monitor. Use of ADS will help ensure that all parties are aware of the presence and intentions of ships in the area and that all are working with the same data; effectiveness of ADS depends on the number of vessels equipped with the system. The Coast Guard is requiring the use of ADS on all tank vessels of 20,000 deadweight tons or more in Prince William Sound, Alaska (33 CFR Part 161, revised July 17, 1992).

Automatic Dependent Surveillance Shipborne Equipment (ADSSE) is carried by vessels participating in an ADS scheme, to provide VTS systems and, if desired, other nearby vessels, with ship surveillance information. This equipment features an automatic broadcast of ship identification, course, speed, and position, derived from an onboard navigation system. The broadcast also could contain intent data based on the next waypoint. The sensor of choice is DGPS equipment with the data is transmitted via VHF radio channel(s). The Coast Guard is requiring ADSSE on tank vessels of 20,000 deadweight tons or more using the VTS system in Prince William Sound, Alaska (33 CFR Part 161, revised July 17, 1992). (See "Vessel Traffic Services.")

Automatic Radar Plotting Aid (ARPA) is a computer that quickly and automatically plots radar targets and is used to assess passing and overtaking situations. ARPA typically obtains information about the course from the gyrocompass, speed from the Doppler speed log, and target positions from a radar, which sometimes is built into ARPA. ARPA can help prevent collisions in open bays and sounds; its collision avoidance feature is of lesser utility in narrow channels (Zabrocky, 1992). This operating characteristic stems from the nature of ARPA, which averages large amounts of inexact data to calculate a target's probable past course and then projects that information into the future; the device simply does not have the resolution to solve problems involving close encounters, nor has the technology been able to generate solutions quickly enough for transits requiring frequent maneuvering, such as in narrow, winding channels in waterways and rivers.

An *autopilot* is a computer that steers a programmed course by sensing deviations from the true course (determined by gyrocompass) and compensating with changes in rudder angle. An autopilot may also be used to keep the ship on a passage plan trackline based on cross-track error information from electronic navigation instruments capable of storing voyage plans. Some autopilots can steer the ship toward a defined waypoint with or without correction for drift but without regard to cross-track error. Some newer systems execute turns automatically with a constant rate or radius to finish at a preset heading or to intersect with the next leg of the voyage plan. Autopilots, in varying levels of sophistication, are in near-universal use on deep-draft vessels.

Beacons are used as lighted and unlighted reference points for ships, to prevent groundings and help with alignment in channels.

Buoys are used as lighted and unlighted reference points for ships, to prevent groundings and help with alignment in channels. Radar-reflecting buoys give an electronically enhanced radar signal.

Constant tension winches are used to maintain pressure on wire ropes holding a ship against the pier as the ship changes draft (due to loading or unloading) and as winds and currents change. With manually adjusted winches, the crew must be alert to adjustments needed to prevent ropes from snapping under excess tension and to prevent the vessel from surging against the dock under slack lines.

A *course recorder* makes a pen-and-ink record on a paper chart roll to record courses steered and course-keeping quality. This equipment is in wide use on deep-draft vessels but a significant number of ships lack this equipment.

Decca is a long-range radio navigation system that is less accurate than the Global Positioning System (GPS). Decca is expected to be phased out around the turn of the century.

The *depth sounder* is used to monitor the depth of water under the keel. It features an analog or digital display of water depth. Some units have a depth alarm feature. This equipment is in almost universal use on deep-draft vessels.

The *Differential Global Positioning System (DGPS)* provides the capability accurate position fixes in harbors and harbor approaches by using data broadcasts (by the Coast Guard in the United States) to correct GPS signals. The DGPS is scheduled to be in place in 1996, when the differential corrections will be transmitted through marine radio beacons located along the U.S. shoreline. The present attainable 2 dRMS (distance root mean square) accuracy of DGPS is roughly 5 to 10 meters (USCG, 1992); accuracy may improve with the next generation of GPS receivers, as receiver errors (noise and multipath) are minimized (Cannon and Lachapelle, 1992). The DGPS is expected to increase the accuracy of vessel navigation, VTS surveillance, and onboard plotting of other vessels (Alsip et al., 1992).

Digital Selective Calling (DSC) is the international standard for data communications in maritime mobile communications service. In the VHF band, DSC is a 1,200-baud, character-oriented data link.

The *Doppler speed log* uses reflected sonic emissions to calculate vessel speed through the water and, in some cases in relatively shallow water, speed over ground. Outputs are used by the ARPA to calculate collision avoidance data and by electronic navigation instruments to calculate set and drift, or for dead reckoning by the ARPA when the water signal is lost. The Doppler speed log features a digital display of speed fore and aft and athwartships. It is in common use, but a significant number of ships lack this equipment.

Dual-Axis Docking Doppler Systems provide two Doppler speed logs, one forward and one aft, configured to measure speed over ground both longitudinally and horizontally. By observing speeds on a combined display, the mariner can control the ship fairly well while docking. These systems are used only on very large ships due to their high cost and marginal utility for smaller ships.

Electrohydraulic Steering Control sends an electric signal from the steering wheel on the bridge to a hydraulic steering engine (which is connected to the rudder) to cause the rudder to move in proportion to the wheel movement.

An *electronic chart* is a digitized version of a nautical chart, with graphic representations of water depth, shorelines, topographical features, aids to navigation, and hazards (Eaton, 1990; Eaton et al., 1990; Gold, 1990b; Landreth, 1991; Rogoff, 1992).

The origins of the electronic chart date back to the use of mechanical plotters by the military during World War II. Video plotters later were developed that used data from Loran C or other continuously operating systems; the addition of coastlines and navigational aids to the video plotter screen led to the evolution of the electronic chart (see Rogoff, 1990). Although the technology has been available for over a decade, interest in electronic charts has soared recently with the availability of reasonably priced computers for rapid manipulation of large amounts of chart data.

At present, electronic charts have no legal status and are used only to supplement paper charts. The SOLAS convention requires that all ships carry charts; although not stated explicitly, it is understood that this refers to paper charts (Mensah, 1990).

An electronic chart offers little improvement over the paper chart unless it is combined with other information or data presentation features. At a minimum, the ship's position (from Loran C or the GPS) and planned track are needed; also useful are an overlay or underlay of a radar image, electronic bearing lines, velocity vectors, ARPA data, and warnings and alarm information (see Electronic Chart System and Electronic Chart Display and Information System [ECDIS]). Use of electronic charts on large commercial vessels has been limited, because international standards have yet to be approved for ECDIS and because of the limited availability of suitable electronic charts.

Electronic chart system (ECS) is a generic term referring to systems that display an electronic chart on a computer monitor. Such systems are *not* the legal equivalent of a paper chart, and the hydrographic data base used need not be "official" (i.e., provided by a national hydrographic office). Electronic positioning is required, and a radar overlay is optional. Such systems are in use on some commercial vessels as a navigation aid, with paper charts fulfilling the legal carriage requirement. Standards for ECS are under revision by the Radio Technical Commission for Maritime Services SC-109 Category 3 Working Group.

An *Electronic Chart Display and Information System (ECDIS)* receives position data from radio navigation instruments and integrates it with a voyage plan and an "official" hydrographic data base to provide a real-time display of the ship's position with respect to the chart and voyage plan. Electronic positioning is required, and a radar overlay is optional. First-generation models are in limited use on some advanced ships (Akerstrom-Hoffman et al., 1993; Alexander and Black, 1993; Ganjon, 1991; Gonin, 1993; Lanziner et al., 1990; Rogoff, 1992; Royal Institute of Navigation, 1993; C. Weeks, 1992).

ECDIS is a specific type of electronic chart system that eventually will use a data base provided by a national hydrographic office[2] and meet international standards. An international evaluation of draft performance standards is underway, and, once generally accepted standards are approved,[3] ECDIS may be considered equivalent to paper charts (Mensah, 1990). (The full planned capabilities of ECDIS are detailed in the *Draft Assembly Resolution, Performance Standard for Electronic Chart Display and Information System,* IMO Maritime Safety Committee, MSC/Circ. 637, May 27, 1994.)

ECDIS is expected to become a basic navigation technology in the future, as radar and voice communications are today. Indeed, some experts assert that it is only matter of time before ECDIS becomes mandatory (CHA, 1990). Draft legislation has been proposed that would make ECDIS mandatory for operations in United States waters. This draft legislation has come under criticism, because requiring specific technology rather than equipment that met performance objectives would be required could potentially constrain the development of electronic positioning systems (Chapter 6).

The *engine console* is used to control the main propulsion system and thrusters. It features *Engine Order Telegraph* or direct throttle control of main engines, lever control of bow and stern thrusters, and readouts of engine performance.

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[2] The National Oceanic and Atmospheric Administration is developing a standardized, fully attributed electronic chart for use in ECDIS, but progress is slow, so leading equipment vendors and suppliers are developing their own electronic charts, which vary in content and completeness.

[3] The earliest this could happen is the IMO General Assembly in the fall of 1995 (Donald Florwick, NOAA, personal communication, October 30, 1992).

Engine order telegraph is in almost universal use on deep-draft vessels, and direct throttle control is in wide use. Thrusters are installed on selected vessels.

Expert systems—see piloting expert systems.

Fog signals are used as reference points for ships in order to prevent groundings and collisions. Signals include the diaphone, horn, bell, whistle, and gong.

The *Global Maritime Distress and Safety System (GMDSS)* is a telecommunications concept for ships that encompasses equipment such as radio communications devices, Emergency Position Indicating Radio Beacons (EPIRB), and satellite terminals. The 1988 amendments to SOLAS specify minimum carriage equipment-based on routes traveled and other variables. The GMDSS is in universal use, effectively making Morse code obsolete (Brodje, 1992; Fairplay, 1992b; IMO, 1986).

The *Global Positioning System (GPS)* is a Department of Defense radio navigation system using transmissions from satellites. It will provide very accurate and continuous worldwide position fixes in three dimensions through its initial constellation of 24 satellites. The GPS is scheduled for initial operational capability by the summer of 1993 and full capability by mid-1994.

For civilian users, GPS provides horizontal accuracy to 100 meters, 2 dRMS (DOT and DOD, 1993), or approximately 95 percent accuracy. This 100-meter accuracy is a result of deliberate degradation of the system by the Department of Defense; normally, accuracy would be in the 20- to 30-meter range (Donald Florwick, NOAA, personal communication, October 30, 1992). To overcome this performance limitation and to minimize other systematic signal errors, GPS can be augmented by differential corrections to its range measurements (USCG, 1992), based on the precise location of a reference antenna. (See Differential Global Positioning System.)

A key feature of both GPS and DGPS is that the equipment is accurate and easy to use, meaning that some traditional navigation skills are not required for its operation. The receivers display latitude and longitude directly, so the user is required merely to plot them correctly or have them displayed on an electronic chart. Moreover, the receivers are small, which facilitates the design of compact navigation stations. The ease of use reduces human collection and processing requirements, thereby providing more time for interpretation and use of navigation information. It also gives the watchstander time to attend to other bridge team tasks.

GLONASS is a Russian satellite navigation system similar to the GPS. It is expected to provide accuracy of about 30 meters without differential corrections (Eastwood, 1990; Kinal and Singh, 1990; Nilsson, 1992).

The *gyroscopic (gyro) compass* uses the spatial stability of the gyroscope to provide a display of true heading. The gyrocompass features azimuth repeaters for visual bearings and course monitoring, and digital repeaters for course monitoring. Outputs from the gyrocompass can provide signals to the autopilot, rate-of-turn indicator, ARPA, electronic navigation instruments, course recorder, satellite communications antenna, and ECDIS; gyrocompass outputs provide heading data for calculating steering corrections, set and drift, rate of turn, dead-reckoned course, and alignment to changes in heading. Gyrocompasses and azimuth repeaters are in almost universal use on deep-draft vessels, and digital repeaters are in wide use.

Hull stress monitoring systems make use of structure-mounted sensors and computer models of the ship hull to provide expert advice on safe speed and heading. These systems help minimize potentially dangerous conditions in severe weather.

An *Integrated Bridge System (IBS)* provides all information essential to navigation and piloting at a central command-and-control station, thereby reducing risk and allowing for reduced crew size. An IBS combines an electronic chart system, a positioning system, and other traditional or newly developed displays, sensors, controls, processors, and panels in one compact console. This console is placed in the area of the bridge that provides the best view for visual lookout, so the ship can be maneuvered by one person, and there is no need to build the complicated and error-prone communication links of the traditional command-and-control chain (see description of the traditional bridge at the beginning of this appendix). The IBS configuration is similar to that of an airplane cockpit, although visibility covers a substantially larger field of view. Some new ships, particularly in Northern Europe, have IBS (Alexander and Spalding, 1993; Gill, 1989; Hederström and Gyldén, 1992; Kristiansen et al., 1989; Maconachie, 1990; Marine Log, 1993; Roeber, 1992).

The *Integrated Ship Control System (ISCS)* is an extension of the integrated bridge concept wherein engineering and cargo/ballast functions are integrated with the navigation systems on the bridge.[4] It is becoming easier to establish links among the various systems, as almost all new ships are built with inte

[4] There is merit in such integration. Coordination between the bridge and the engineering plant is needed to ensure proper control of the engines, including anticipation of pending changes in speed or direction. The safe maneuvering of the ship also demands proper management of electric power, control air, and starting air resources. Likewise, to provide and maintain proper trim and stability, the crew needs to control ballast and cargo levels. Ideally, all information and operating functions needed while the ship is underway could be placed in a single console at the normal maneuvering position.

grated, digital engine-control systems and many utilize similar systems for cargo and ballast control. Several ships with ISCS technology have been built by several foreign operators (Herberger et al., 1991; Kristiansen et al., 1989; O'Neil, 1990). In these ships, the engine, ballast, and cargo control consoles have been relocated to the bridge.

Some existing ships with ISCS are operated by specially trained dual-purpose officers, while other ships retain the traditional split between the deck and engine crew (i.e., the deck officer must call for an engineer when an engineer is needed). If fully integrated systems and one-person bridge operation become feasible, then operating requirements and ship design would have to be evaluated very carefully, and the single watch officer would need a new range of skills and training. Of particular concern would be the design of the ship and its systems to prevent an overload of information and work on the watch officer. New technologies are being developed to address these concerns (see "Piloting Expert Systems").

Lights are used as shore reference points for ships, both to prevent groundings and to help with alignment in channels. Lights include fixed light structures, major floating lights, and ranges (e.g. lights in line).

Loran C is a radio navigation system that provides latitude and longitude coordinates for harbors and their approaches, with accuracy of 0.25 nmi (2 dRMS) or better (DOT and DOD, 1993). (The Loran's repeatability is significantly better than its accuracy.) The Loran is used to fix navigational position. It is in wide use on deep-draft vessels.

The *magnetic compass* is used primarily to set and monitor the gyrocompass, but it also may be used as the primary heading instrument. The magnetic compass typically is mounted on the flying bridge with periscope viewing. It is in almost universal use on deep-draft vessels.

The *nautical chart* is a graphic representation on paper of navigable waters, showing water depth (by soundings or depth contours), shorelines, topographic landmarks, aids to navigation, hazards, and other information of interest to mariners. Many vessels are required by law to carry nautical charts, which are in universal use.

Omega is a long-range radio navigation system with accuracy of 2 to 4 nmi. Differential Omega has an accuracy of 0.3 nmi within 50 nautical miles of a reference antenna, and 1 nmi at 500 nautical miles (DOT and DOD, 1993). It is not widely used and is expected to be phased out around the turn of the century.

The *Physical Oceanographic Real-Time System (PORTS)* is a technology devel oped by the National Ocean Service that is designed to overcome limitations of traditional prediction tables (published annually) that provide only the astronomical tides and currents. The system employs sensors placed at multiple locations within a port to measure real-time water level, current velocity, wind velocity, and water temperature. The initial test installation in Tampa provides data on hourly radio broadcasts and allows real-time voice data to be received by telephone or text data to be received by telephone modem (Appell et al., 1991; Bethem and Frey, 1991; Frey, 1991; NOS, 1990).

Piloting expert systems are computer programs designed to combine the knowledge and reasoning process of expert operators and to recognize the need for advice and provide it. Real-time input from numerous sensors is required for these systems to recognize and interpret the need for advice. Shipboard piloting expert systems are under development in many countries as part of "intelligent" ship projects (Grabowski, 1987, 1989, 1990; Hartman, 1990; MARAD, 1988). The very comprehensive U.S. Shipboard Piloting Expert System (SPES) is an intelligent node in an IBS.[5] In addition, a number of stand-alone systems are being built by a variety of manufacturers in the United Kingdom, Norway, the European Community (the *Expirt KBS* Ship Project), Germany, Japan, and South Korea (Iijima and Hayashi, 1991).

The *Portable Communication, Navigation, and Surveillance (PCNS)* system is conceived as a small unit that could be carried aboard vessels by a pilot. The primary components are a DGPS receiver with an electronic chart display and a VHF radio. The PCNS would provide many of the benefits of ADS before widespread implementation of ADS systems. A number of pilot organization and instrument manufacturers have shown interest in developing and testing this concept.

Numerous *publications* are essential to navigation. The *Local Notice to Mariners*, published by each Coast Guard district, contains chart corrections and other information of local and wide interest. (Summaries are contained in *Weekly Notice to Mariners*, published by the Defense Mapping Agency Hydrographic/Topographic Center.) *Tide Tables and Tidal Current Tables* is produced annually by the National Oceanic and Atmospheric Administration (NOAA); the information also may be obtained by modem.

A series of nine *U.S. Coast Pilots*, published regularly by NOAA, provides information on domestic navigation regulations, outstanding landmarks, channel

[5] The Shipboard Piloting Expert System program, under development by Rensselaer Polytechnic Institute, is sponsored by the Maritime Administration and the Coast Guard, with cost sharing by Sea-River Marine (formerly Exxon Shipping Company) and Sperry Marine.

peculiarities, dangers, weather, ice, port facilities, and other features of interest. Similar information for waters outside the United States can be found in *Sailing Directions*, revised as needed by the Defense Mapping Agency Hydrographic/Topographic Center. The rules of the road for navigating inland U.S. waters and the high seas can be found in *Navigation Rules*, published by the Coast Guard. The *Nautical Almanac*, published annually by the Naval Observatory, contains astronomical information needed for celestial navigation. The *Light List*, published annually by the Coast Guard, contains information on lights and sound signals, unlighted buoys, radiobeacons, radio direction finder (RDF) calibration stations, racons, and Loran stations in U.S. coastal waters, the Great Lakes, and the Mississippi River. Similar information for other coasts can be found in the *List of Lights*, published annually by Defense Mapping Agency Hydrographic/Topographic Center.

Racons are aids to navigation that give an electronically enhanced radar signal. Also known as radar transponder beacons, racons may respond with Morse code in the 3 cm or 10 cm bands.

Radar, second only to the gyrocompass, is probably the most important traditional aid to navigation available to the marine pilot. Radar can measure range and bearing accurately and quickly and can feed data to other equipment, such as ECDIS. Existing radar technology is not wholly adequate, however. Pilots responding to the committee's correspondence said their most pressing technological need was for a highly improved radar system, particularly with improved target acquisition during squalls (Ramaswamy and Grabowski, 1992).

Radar marks are used as shore reference points for ships, to prevent groundings and to help with alignment in channels. Such marks include ramark (radar beacon transmitting continuously), racon, radar reflectors, and the new circular polarized radar reflectors (used with a special radar for accurate positioning in piloting waters).

Radio beacons are AM radio stations used with radio direction finders on ships. The position fixes provided by this system no longer meet modern requirements, but, as the system has been chosen to carry DGPS broadcasts, it is likely to continue in use.

The *Radio Direction Finder (RDF)* is a short-range navigational aid using radio beacon bearings that is used to fix navigational positions. The RDF is installed widely, but its utility is diminishing with the advent of more sophisticated aids.

The *rate-of-turn indicator* uses outputs from the gyrocompass or an internal gyroscope to display the rate (in degrees per minute) at which the ship is chang ing heading. The display may be analog or digital; most of these indicators also provide an audible report. This indicator is in wide use on deep-draft vessels; however, a significant number of ships lack this equipment.

The *recording barometer* measures and records, on a chart, the atmospheric pressure. By observing the pressure and rate and direction of change, the watch officer can predict changes in weather and the likely severity of the weather.

Repeaters are displays showing information from remote instruments.

The revolutions-per-minute (RPM) indicator is used to monitor the propulsion system. It features an analog or digital display of engine, shaft, or propeller RPM. It is in almost universal use on deep-draft vessels.

Routes—see tracks.

The *rudder* is a flat structure of wood or metal attached vertically to the ship's stern. The rudder is used for directional control of the vessel; when it is turned, the ship's bow turns in the same direction.

The *rudder angle indicator* is used to monitor the rudder. It features an analog display in degrees. It is in almost universal use on deep-draft vessels.

The *steering stand* is a console where the steering wheel, rudder angle indicator, autopilot, and backup steering systems are mounted. This equipment is used for course keeping and navigation and is in almost universal use on deep-draft vessels.

Tide Tables—see publications.

The *tiller* is a lever used to turn the rudder in steering.

Tracks and *routes* are used for safe routing of ships, to prevent collisions and groundings. Tracks and routes include traffic separation schemes, precautionary areas, inshore traffic zones, deep-water routes, and recommended routes. Tracks and routes are especially common in port approach and coastal confluence areas.

Transit (Navy Navigation Satellite System, or NAVSAT) is the original satellite navigation system. It consists of five satellites orbiting the Earth at an altitude of almost 700 miles. Transit is used for position fixing on many seagoing vessels. Its accuracy varies from 25 to more than 500 meters, depending on the equipment and the user's knowledge of the ship's velocity. System coverage is global, but not continuous (DOT and DOD, 1993). The system probably will be phased out slowly in preference to the GPS. (The 1992 Federal Radionavigation Plan [DOT and DOD, 1993] calls for termination of Transit in December 1996.)

Vessel Traffic Service (VTS) systems are a form of marine traffic regulation. VTS overlays a port and waterways complex with an organizational structure that enhances communication and interdependent decision-making between vessels, improves order and predictability, and provides a capability for real-time operational oversight and traffic management by port safety and management authorities. This structure may be enhanced by establishment of traffic lanes where feasible. A VTS provides information to vessels in transit about vessel traffic and other hazards in waterways, harbors, and harbor approaches and, depending upon the operational concept employed, may also provide advice or conduct traffic or anchorage management. (For an extensive discussion of VTS, see Chapter 5.) (CCG, 1992; Cutland et al., 1988; Glansdorp, 1987; Herberger et al., 1991; Hofstee, 1990a; Ives et al., 1992; Maio et al., 1991; Mizuki et al., 1989; Polderman et al., 1990; Young, 1994.)

Weather facsimile receivers can be programmed to receive forecasts and weather maps of the area in which a vessel is sailing. They produce printed copies of this information, allowing the mariner to study the data and plan route changes or other preparations for expected weather conditions.

Weather routing services provide weather monitoring and prediction assistance as well as recommendations for changes in voyage plans to avoid severe weather or to take advantage of (or avoid) ocean currents. These services have been shown to save time and fuel in long ocean passages and to reduce costs related to damage and repair.

Appendix H

Summary Report of European Trip

European Ports as Integrated Systems

Each port and river system on the committee's itinerary essentially functions as an integrated system under the oversight or substantial influence of a single harbormaster who wields considerable authority. The pilots do not work for the harbormaster but are, in effect, major players on his team. The pilots are entrusted with ensuring the safety and efficiency of vessel operations, and they work in very close consultation and cooperation with port authorities. Pilots tend to be market oriented, but not at the expense of safety.

In the Netherlands, where there is tremendous societal concern for safety and the environment, the balance between safety and efficiency seems to vary by port. In Rotterdam, where safety is an economic issue (10 percent of the nation's gross national product comes from the port's activity), efficiency appears to have the edge.[1] In the River Scheldt system, at least in Dutch waters, safety is the principal concern, largely because most of the traffic is destined for upstream Belgian ports (which compete with Rotterdam for container cargoes) and because large gas carriers pass within half a mile of the Dutch city of Vlissingen (Flushing). Safety is the primary focus of the Amsterdam Port Authority, because most of the port activity there is private.

[1] The first phase of the Rotterdam Port Authority safety study was completed recently. A copy (in Dutch) was made available to the delegation. Basic findings were that 60 percent of accidents occur in basins (including dockings and undockings) and 40 percent in fairways. In later phases of the study, safety policy will be considered for shipping traffic and transport of dangerous goods.

Pilotage

Heavy emphasis is placed on the professional competence of pilots in Western European and Scandinavian waters. The qualification program in Rotterdam is perhaps the most rigorous, requiring theoretical, simulator, and practical training and examinations, but all pilotage authorities require considerable experience and apprenticeships.

Pilotage systems are undergoing significant changes. In the Netherlands, for example, the Rotterdam-Rijnmond Pilots (Maas Pilots) L.R.R. and other pilot organizations were privatized in 1989 to improve the efficiency of the pilotage service. Previously, the river pilots were employed by the government and the harbor pilots by the Rotterdam Municipality, which is reflective of the historical government structuring and organization of Dutch society. The pilots think they provide better service now, and they are working very hard to smooth out wrinkles in the system.

Rotterdam-Rijnmond Pilots reported that they have to be market oriented; ship owners want value for their money. Everyone wants all-weather service and no unnecessary delays. The port wants efficient pilot service to maintain its competitive edge. The pilots must be sensitive to all these interests, albeit not at the expense of safety. The pilots see themselves as key instruments for achieving operational safety in the port complex.

The U.K. pilotage system was revised as a result of the Pilotage Act of 1987. Under the old Trinity House system, all pilots were self-employed and entitled to charge whatever the market would bear. Parliament felt the pilots were making port operations too expensive; Prime Minister Thatcher produced the Pilotage Act, with input from pilots. The Port of London Authority (PLA) Pilotage Service now employs the pilots, who are unionized. The port employed a computer model to determine how many pilots were needed in the region. Of the 300 pilots in the Trinity House system, 180 were selected. The remainder were retired. At the time of the delegation's visit, there were 114 pilots (90 sea and 24 river).

Many European pilots wear uniforms. Pilots in the Netherlands wear a prescribed uniform consisting of black trousers, white shirt with shoulder marks, and black coat. In the Port of London, the prescribed pilot uniform is black pants with a white shirt and shoulder marks.

The European approach to safety sometimes demands two pilots per vessel. In Sweden, for example, ships greater than 60,000 deadweight tons (DWT) require two pilots. One is for handling communications!

Only highly skilled, senior pilots are qualified to handle the very large crude carriers (VLCC) calling at Rotterdam. Captain Robert Hofstee arranged for Admiral Herberger to accompany him and a second pilot on a VLCC transit from sea into Europort. The VLCC was about 269,000 DWT and drew 68.5 feet of water (the channel was 70 feet deep). One pilot conned the vessel, while the second pilot performed navigation duties using the ship's radar and pilot-provided portable Decca navigation aid. The senior pilot commented that some ships arrive at Rotterdam with too few crew members to handle the tug lines in an expeditious manner. This is a safety concern that pilots and port officials are reviewing.

Throughout Europe, small commercial craft and some coasting vessels generally are exempt from compulsory pilotage. Exemptions from compulsory pilotage generally are available to European Community (EC) flag ships on set runs (e.g., North Sea Ferries). However, exemptions are controlled tightly, are usually vessel and route-specific, require frequent trips, and usually require that the master or mate be subjected to a rigorous practical or theoretical examination, or both. (For smaller vessels, exemptions may be based on vessel size or operator experience.) Essentially, those receiving exemption certificates are required to have the same professional qualifications as are pilots, although only for a certain route and ship type and size. Exemption programs are intended to provide a baseline level of pilotage competence for all vessels (Herberger et al., 1991; Hofstee, 1990b).

Captain Hofstee reported that the European Maritime Pilots Association, of which he is president, believes that too much is expected of shipmasters. The association argues that pilotage exemption can be a detriment to safety, particularly where certificate holders are aboard vessels underway less than 24 hours between two ports. Captain M. Nauta, senior master, North Sea Ferries, noted that the Rotterdam Port Authority (RPA) can override the pilotage exemption if circumstances warrant. For example, a pilot and tugs are required under certain wind conditions.

European pilots generally felt that the quality of merchant mariners has been slowly declining. The trend is unevenly distributed; it is more noticeable on ships of some (unspecified) Third World nations and of certain companies that are cutting costs to bare minimums. Pilots also noted that the drastic changes in the structure of Eastern Europe are having some effect on the quality of merchant marine personnel, essentially because wage-earning opportunities at sea often are better than those available in the homeland. As a result, there has been an apparent increase in Eastern Europeans from non-nautical backgrounds on some ships. How, or to what degree, such developments might translate into safety problems is not known. Captain Hofstee observed that, in the future, there will be a greater need for pilots to offset the general decline in professional qualifications of bridge crews.

Pilot Training Using Shiphandling Simulation

European pilot training emphasizes apprenticeships and, to a lesser degree, shiphandling simulation. The primary training method is apprenticeships, which provide exposure to a wide variety of vessels under a wide range of operating conditions, thereby enabling pilots to mature through progressive accumulation of local knowledge and professional expertise. This experience often is enhanced with shiphandling simulation, which generally is considered a valuable training aid.

BOX H-1 ITINERARY

July 22	Port Revel Center	Full delegation	Lectures & Shiphandling
July 23	Rotterdam Pilots	Full delegation	Presentations
	Rotterdam Port Authority	Full delegation	Presentations
July 24	Rotterdam Port Authority	Full delegation	VTS briefing and visit
	Flushing VTS	Full delegation	VTS briefing and visit
July 25	Rotterdam Pilots	Individual members	Observe pilot boat operations
	Rotterdam Port Authority	Individual members	Presentations
July 26	Rotterdam Port Authority	Individual members	Presentations
	London Port Authority	Individual member	Port of London pilotage
	Gothenburg Pilots	Individual members	Pilotage in Sweden
	Gothenburg VTS	Individual members	VTS briefing and visit
	Very large crude carrier (VLCC) transit	Individual member	Participate in helicopter pilot embarkation and observe VLCC piloting
July 27	London VTS	Individual members	VTS briefing and visit
	M/V Wellamo	Individual members	Observe ferry piloting through archipelago
July 28	*M/V Silja Symphony*	Individual members	Observe ferry piloting with latest technology electronic systems
July 29	Helsinki Pilots	Individual members	Discussions
	Ship Simulation Center	Individual members	Briefing and visit

In Finland, computer-based simulation training is mandatory; pilots must undergo retraining every 3 years. The Rauma Maritime College in Helsinki operates the training facility, which is funded by the government. Simulator time is allocated 70 percent to training and 30 percent to research. The college is unique in that it certifies ferry masters for pilotage exemption based on the results of simulation tests.

Where employed, simulations build on and help refine an individual's existing capabilities, and, if combined with theoretical classroom work, they provide primers or refreshers on technical matters. This is because, regardless of whether physical scale-model or computer-based simulations are used, all pilots or pilot candidates acquire considerable nautical experience before participating in a simulation. No organization was found to be using simulations as a shortcut in pilot training.

Opinions varied widely concerning what simulations and simulators provide, at what stage in professional development they should be used, and for what purposes. Generally, manned-model simulators—such as those employed at Port Revel, France (visited by the delegation), and Southampton, England (discussed by pilotage authorities)—provide a means to acquire a "feel" for how vessels respond, using all the physical senses needed in shiphandling under actual environmental conditions. Although simulators do not compensate for some scale effects (particularly in shallow water), the general belief is that such effects are small and do not compromise the medium for training purposes.

There is no consensus on the degree to which the Port Revel facility—which offers a more complete hydrological profile than does Southampton—may provide for a more faithful reproduction of ship behavior for maneuvers in shallow and restricted water that does the Southampton facility. There is agreement that Port Revel is more expensive, and that this has influenced some shipping companies to send their personnel to Southampton rather than to the more complete facility at Port Revel. Pilots, particularly from the United States, have begun attending Port Revel in increasing numbers. Pilots from London, however, go to Southampton, largely because the PLA regards this facility as satisfactory (other factors include cost, convenience, and national loyalty).

Port Revel takes four to eight students per week, except during the winter, when the facility is closed. Total cost of training is about $10,000 plus transportation. During the past 25 years, 3,600 mariners have been trained; as of the delegation's visit, 974 were pilots. In the past, most of those attending have been ship masters, but the balance is shifting toward pilots.

Europeans generally agree that computer-based simulations can be effective for training in procedures and emergency scenarios in a compressed time frame without exposure to actual risk. From the pilot's perspective, the simulators are not useful for learning bridge team management; that is because pilots deal principally with foreign-flag ships, which pilots reported frequently have nothing resembling a bridge team. Therefore, teamwork training using simulation for such situations would have little relevance. The effectiveness and acceptability of computer-based simulations for developing shiphandling knowledge and practicing shiphandling skills is a controversial issue. The debate cuts across both user and non-user groups; even those who have used simulators disagree among themselves.

Rotterdam pilots used the computer-based simulator at Wageningen, the

Netherlands, for pilot candidate and VLCC shiphandling training.[2] J. Lems, RPA deputy director of shipping, observed that the development of simulators must involve pilots. Captain W. Ph. van Maanen said that there should be some type of reference booklet, so trainees could check on why things went wrong (or right) and what was learned. In simulation training supported by RPA, debriefs are part of the program, but Captain van Maanen observed that nobody seems to do a good job evaluating the results.

Captain Hofstee noted the Rotterdam VLCC pilots undergo emergency training every 2 years because of the significant risk to the environment associated with VLCC cargoes.

Vessel Traffic Services

Substantial investments have been made in vessel traffic services (VTS), both to enhance the economic efficiency and competitive advantage of specific ports (e.g., to give Rotterdam an edge over Antwerp) and to benefit safety and the environment. The VTS investment is especially large in Holland, where port operations contribute significantly to local and regional economies and the gross national product, and there is considerable concern for public safety and environmental protection. On the other hand, Finland has no VTS systems. The Helsinki port director characterized VTS as "a hole into which one pours money."

The VTS systems in the major ports and river systems serve as the harbor-master's eyes and ears as well as the command center for governing vessel traffic management and coordinating crisis response. No one is really sure whether VTS systems achieve economic or safety objectives, but the perceived need for a businesslike approach to traffic management and safety is strong enough to underwrite support for the systems.

At Rotterdam, the vessel traffic management system (VTMS)[3] was developed to replace a radar system in order to cope with ever-larger vessels, increased traffic, and increasingly dangerous goods. The system is a joint venture of the Ministry of Transport and the port. The VTMS is designed to provide all activities necessary to achieve a safe and efficient traffic flow to and from the

[2] The Dutch are reasonably comfortable with the technique and also employ it for channel design (the RPA recently used the Marine Safety International [MSI] facility in Newport, Rhode Island, for this purpose). Captain W. Ph. van Maanen noted that RPA pays for one week (40 hours) of simulator training for users of new basins. A major new simulation facility is scheduled to open in Rotterdam in May 1994.

[3] The Dutch have also built a system to enable authorities to monitor the extensive inland waterway system of canals and locks. Some parts of the system have radar and/or closed-circuit television. Because of existing legislation, the system cannot provide traffic guidance but it can give traffic information.

Port of Rotterdam (and Europort).[4] The system consists of a main Harbour Coordination Center (which coordinates the work of the entire VTS), as well as three traffic centers (Hoek, Botlek, and Stad), two subtraffic centers (mainly used to support inland traffic), patrol boats, pilots, boatmen, tugs, customs, and immigration.

Captain S. N. Zuurbier, president of Reg. Loodsencorporatie Rotterdam-Rijnmond, said pilots initially feared that modern electronics would threaten the existence of the profession. "By now that fear has disappeared entirely …. The harbormaster (now) has two instruments to guarantee the safe and smooth handling of traffic: these are the traffic service and the pilot service. Both are complementary and can no longer be separated from the site of operations" (S. N. Zuurbier, personal communication, July 23, 1991).

The Flushing VTS is an unusual case of international cooperation. Both Dutch and Belgian pilots are to provide support at the main traffic center, but the Belgians had not yet obliged, although there were lower-level Belgian watch personnel. At the Scheldt Coordination Centre, decision-making about crises is supposed to be done by consensus and coordinated with Belgian authorities. Since 1985, the crisis management group has been brought together only three times. The governor of the Dutch province affected can override a decision by VTS, as can his Belgian counterpart. Regarding safety performance, there have been approximately 20 accidents in 6 years of service. Some pilots think there is too much control and that everything was fine without the VTS. There is some apprehension over pilot job security with the increasing involvement of shore-based personnel.

The professional backgrounds of European VTS watch personnel and controllers range from no nautical experience to licensed pilot. The majority of VTS personnel have maritime experience in commercial or government service. There is a trend toward placing pilots in traffic centers to provide a resource for technical harbor expertise. Generally, pilots staff some VTS positions on a limited basis at critical points in the waterway system. When doing so, pilots are responsible to the harbormaster operating the system and to the person in charge of the center or watch (who could be the pilot). Some VTS systems actually are operated by pilots; such systems are generally staffed by members of the pilot associations or by semi-retired association members.

the form and manner of VTS training varies widely. The Netherlands has

[4] While most of the port is adequately covered by radar, the overall electronic display system and automatic tracking capability is not fully functional, principally because the Dutch government required that the electronics be of Dutch origin. As there were no off-the-shelf Dutch VTS electronic systems, the prime contractor, Philips, had to invent the system, including some technologically advanced portions of the system that were developed as basic system components were being installed and operated.

made a national commitment to VTS and runs a national training program, which includes a VTS simulator at Wageningen. Regional and local (including on-the-job) training follows national training. All candidates have maritime backgrounds. (Note: The Rotterdam Port Authority and Marine Safety Rotterdam have constructed a major ship bridge and VTS simulation facility in Rotterdam. National VTS training will be shifted to this new facility [Van Horssen, 1992].)

The Netherlands National VTS Operator Training Program was described to the committee's delegation by Henk Regelink, course director. At the time of the delegation's visit, 57 trainees had taken the basic course. The objective is a single, national approach to VTS communications. That means there is a need for "attitude" training. The course is rigorous: performance is measured every 3 weeks and there is a 70-percent washout rate. There is some consultation with industry on VTS examination development. For example, the head of the Dutch Ship Masters Association is involved in the process. The quality of VTS simulation training depends on the quality of the trainers. It became obvious through discussion that not all Rotterdam pilots are satisfied with the content of VTS training. Director Regelink indicated that his organization plans to conduct a user satisfaction survey once law is enacted requiring each VTS operator to undergo a practical examination every 3 years.

VTS training in the rest of Europe is port-specific, consisting primarily of local on-the-job training programs. The London VTS has been staffed by the same personnel for years and only recently has had to recruit new personnel. The training program was created coincidentally with the recruitment process and is evolving. Women were recruited actively, because their voices tend to be clearer on the radio and, according to experience in the VTS, women do not get excited during emergencies.

Shore-based pilotage (or passage-assisted transits) are provided on a limited basis under very select criteria from certain VTS centers in rotterdam, River Scheldt, and London using pilots specially qualified for this purpose. There was general agreement that, except for these services, a VTS should not issue maneuvering orders to a vessel. The delegation was told, however, of one worst-case scenario in the Thames estuary during the 1970s when, after a pilot died, a female watchstander at the London VTS, supervised by a veteran VTS controller, effectively guided a foreign vessel with severe language incompatibilities to an anchorage to await arrival of a replacement pilot. The female voice in conjunction with the woman's calm demeanor on the radio allowed the VTS to gain the ship captain's attention.

Captain Hofstee reported that shore-based pilotage is undergoing European assessment. The northern consortium (the United Kingdom, the Netherlands, Finland, and Norway) is conducting fundamental research, while the southern consortium is looking at long-term implementation of shore-based pilotage.

Regarding VTS interventions to prevent accidents, there was general agreement that a VTS should provide timely and accurate information and should correct any obviously erroneous information detected from radio conversations. Whether or to what degree a VTS should intervene proactively is an open question. In Rotterdam, the pilots are firm in asserting their responsibility for the efficiency and safety of vessel operations; they want correct traffic information upon which to act. The Rotterdam VTS appears not to take a proactive role. Because safety is the driving force for VTS in Dutch waters of the river system, the River Scheldt VTS is more likely than others to intervene to the point of providing navigational advice (something short of maneuvering orders). However, a pilot is usually available in the center and would be able to assist.

If trouble begins on the water, the Flushing VTS is obliged to intervene because of oversight expectations from the Dutch marine courts, which can suspend or take away licenses. There is special training on how to give information, beginning with the International Maritime Organization (IMO) guidelines. If necessary, the VTS gives warnings preceded by "Attention!" The VTS tapes voice and digitized radar of all near-misses on the system. This material is available for marine accident investigations *and also is used for training and learning purposes*.

In London, no pilot was assigned to the VTS although the pilot dispatch office is in an adjacent building. (A pilot position is being added at the center now that the pilots are employees of the port authority). The London VTS will intervene to the point of providing navigational information. During the delegation's visit, an inbound tanker lost its radar in fog. The pilot was very willing to accept navigational advice from the VTS watch in the form of periodic range and bearing to anchorage. Pilot acceptance has been a slow process but today pilots make demands on the system.[5] Acceptance of VTS by users was characterized as high.

"Space management" within European VTS systems appeared to the committee's delegation to rely on pilot-initiated actions, except during exceptional circumstances when systems operated by port authorities become more involved. The nature and extent of VTS interventions also appears related, to some degree, to the personalities of the harbormasters and their understanding of their role and responsibilities.

VTS Initiatives of the International Association of Lighthouse Authorities

The International Association of Lighthouse Authorities' (IALA) guidelines for VTS were adopted by IMO in 1978. Today, these guidelines are being com

[5] Since the delegation's visit, arrangements have been made for pilots to become more involved in the VTS systems operation (I. M. H. Slater, Thames Navigation Service, personal communication, June 29, 1993).

promised, and the IALA VTS committee is determining what revisions are needed. Revisions to the IALA VTS definition will specify that a VTS must have a capability to interact with and respond to vessel traffic and must be dedicated to the traffic.

Committee work is accomplished in work groups. Captain G. Kop, chairman of the IALA VTS committee, made the following observations on work group activities:

- *VTS communications procedures*. Most procedures are laid down in international law, but there is a high degree of diversity nevertheless. Basic work is being done on communications procedures.
- *VTS recruitment and training*. This group has accomplished a lot. There will probably be an IMO resolution in 1992 or 1993 on the topic. Training would include validation.
- *Identification and tracking systems*. The group is looking at requirements, capabilities, speed, and what a system should do or not do. Regarding automated reporting and information systems (ARIS), prototypes are being developed by Germany and Norway, and the United States is interested as well. These three nations and Holland are represented on the working group. Radio frequency allocation is an active issue. Holland is thinking about installing ARIS on its Coast Guard cutters.
- *IALA/IAPH/IMPA VTS guide*. The guide has already been produced, and the binder is given at no cost. Port-specific information is given at each port. There is a standard format (Weeks, 1992b).
- *VTS cost–benefit calculations*. This is a long-term development project.
- *VTS environmental aspects*. Integration of operational and safety data from multiple locations on coastwise shipping is under consideration. An information source of this type would provide a more complete basis for marine safety activities.
- *VTS legal*. This group is conducting a long-term review of legal issues. The IALA committee, at the request of IMO, is developing proposed changes to IMO's VTS guidelines (IMO, 1985a).

Glossary

ADS	Automatic Dependent Surveillance
ADSSE	Automatic Dependent Surveillance Shipborne Equipment
AIMS	American Institute of Merchant Shipping
APA	American Pilot's Association
ARPA	Automatic Radar Plotting Aid
ATC	Air Traffic Control
AWO	The American Waterways Operators
CAORF	Computer Aided Operations Research Facility
CASMAIN	U.S. Coast Guard automated main casualty data base
CBO	Congressional Budget Office
CCG	Canadian Coast Guard
CCIR	International Radio Consultative Committee
CFR	Code of Federal Regulations
CHA	Canadian Hydrographic Association
COLREGS	International Rules for the Prevention of Collisions at Sea
COTP	U.S. Coast Guard Captain of the Port
C^3I	Command, Control, Communications, and Information
DGPS	Differential Global Positioning System
DMA	Defense Mapping Agency

DMAHTC	Defense Mapping Ageny, Hydrographic/Topographic Center
DOD	Department of Defense
DOT	Department of Transportation
dRMS	Distance/root mean square
DSC	Digital Selective Calling
DWT	Deadweight Tons
EC	European Community
ECDIS	Electronic Chart Display and Information System
ECS	Electronic Charting System
EOT	Engine order telegraph
EPIRB	Emergency Position Indicating Radio Beacons
FCC	Federal Communications Commission
FR	Federal Register
GAO	U.S. General Accounting Office
GLONASS	Global Orbiting Navigation Satellite System
GMDSS	Global Maritime Distress and Safety System
GPS	Global Positioning System
GYRO	Gryoscopic compass
GYRO-COMPASS	Gyroscopic compass
HDOP	Horizontal-dilution-of-perception
H/T	Ration of water depth to draft
IALA	International Association of Lighthouse Authorities
IAPH	International Association of Ports and Harbors
IBS	Integrated Bridge System
ICAO	International Civil Aviation Organization
ILU	Institute of London Underwriters
IMO	International Maritime Organization (formerly Inter-Governmental Maritime Consultative Organization—IMCO)
IN-MARSAT	INMARSAT (formerly International Maritime Satellite)
IPO	Inputs, processes, and outputs
ISCS	Integrated Ship Control System
MARAD	Maritime Administration
MARGRAD	Maritime Graduate program
MERPAC	Merchant Marine Personnel Advisory Committee
MSIS	Marine Safety Information System

MTRB	Maritime Transportation Research Board
NAD	North American Datum
NAP	National Academy Press
NAS	National Academy of Sciences
NAVSAT	Navy Navigation Satellite System (also referred to as TRANSIT)
NEMA	National Electronics Manufacturing Association
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Survey
NRC	National Research Council
NRDC	Natural Resources Defense Council
NTSB	National Transportation Safety Board
OCMI	Officer in Charge of Marine Inspection
OPA 90	Oil Pollution Act of 1990 (P.L. 101-380)
OSIR	Oil Spill Intelligence Report
OSPR	Office of Oil Spill Prevention and Response, State of California
PCNS	Portable Communications, Navigation, and Surveillance system
PLA	Port of London Authority
PORTS	Physical Oceanographic Real-Time Systems
PSVTS	Puget Sound Vessel Traffic Service
RDF	Radio Direction Finder
RPA	Rotterdam Port Authority
RPM	Revolutions per minute
RTCA	RTCA (formerly Radio Technical Commission for Aeronautics)
RTCM	Radio Technical Commission for Maritime Services
SARPS	International performance standards and recommended practices
SATCOM	Satellite Communication
SOLAS	Society of Naval Architects and Marine Engineers
SOLAS	International Treaty for the Safety of Life at Sea
SPES	Shipboard piloting expert system
TBS	Temple, Barker and Sloane
TDMA	Time division multiple access
TRANSIT	Navy Navigation Satellite System

UNEP	United Nations Environment Programme
USACE	U.S. Army Crops of Engineers
USC	United States Codes
USCG	U.S. Coast Guard
VHF	Very High Frequency
VLCC	Very Large Crude Carrier
VTC	Vessel Traffic Center
VTS	Vessel Traffic Service

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