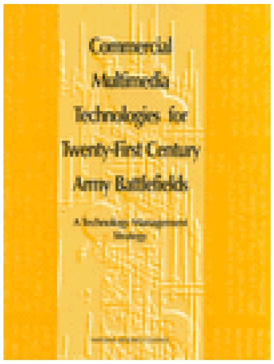

Commercial Multimedia Technologies for Twenty-First Century Army Battlefields: A Technology Management Strategy

Committee on Future Technologies for Army Multimedia Communications, National Research Council

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A Technology Management Strategy

Committee on Future Technologies for Army Multimedia Communications
Board on Army Science and Technology
Commission on Engineering and Technical Systems
National Research Council

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Preface

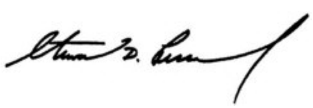
Our report responds to a request by the Army to have the National Research Council study the applicability of commercial multimedia technologies to Army command, control, communications, and intelligence needs on future battlefields. Our committee, known as the Committee on Future Technologies for Army Multimedia Communications, was formed under the auspices of the Board on Army Science and Technology to carry out the study.

Our first meeting was held in September 1994 at Fort Gordon, Georgia. Over the course of the study, three more meetings of our full committee took place. In addition, there were several data-gathering sessions attended by one or more of our members. (See the Appendix for a detailed listing of all meetings and the persons and groups that were involved.)

The committee set up an electronic mail "exploder" after its first meeting at Fort Gordon, which allowed the committee to correspond collectively on an ongoing basis throughout the study. This was used by committee members to share ideas about the structure and content of the report, to exchange drafts of sections and comments on these drafts, and to propose changes in response to reviewers' comments. The committee also made use of multipoint teleconferencing throughout the study to discuss and resolve issues. Thus the committee made good use of some of the information technologies about which it was preparing to advise the Army.

We have structured our findings to be as useful as possible to the leaders, administrators, and managers who will take the Army into the twenty-first century. Our report shows that we believe the commercial multimedia technologies that now exist or are emerging can greatly benefit the Army of the future. The key to realizing these benefits will be for the Army to devise ways to accommodate the very rapid pace of change that is taking place daily in the civilian world of information handling and processing.

We were fortunate to have as members persons with strong representation from that part of the commercial sector involved in advanced telecommunications and computer-based applications. We were also fortunate to have members steeped in the ways of the Army and in military research and development. However, we could not have completed this study without the unfailing cooperation of the many Army personnel, from the Chief of Staff down, who explained the Army to us in ways that we all could grasp. To those Army representatives we are especially grateful.



Stewart D. Personick

Chairman

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Acronyms

ALMOND	Active matrix liquid crystal display
AMPS	Advanced Mobile Phone Service
ANSI	American National Standards Institute
ARDIS	Advanced Radio Data Information Service
ARPA	Advanced Research Projects Agency
ATM	Asynchronous transfer mode
C^{3}I	Command, control, communications, and intelligence
CCD	Charge-coupled device
CMA	Code division multiple access
CEO	Common Operating Environment
CORBA	Common Object Request Broker Architecture
COTS	Commercial off-the-shelf
CPU	Central processing unit
DS	Direct Broadcast Services
DE	Distributed Computing Environment
DES	Digital Encryption Standard
IDS	Distributed Interactive Simulation
DOD	Department of Defense
DRAM	Dynamic random access memory
DEI	Electronic data interchange
EM	Electromagnetic pulse
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GUI	Graphical user interface
HDTV	High definition television
HLR	Home Location Register
IEEE	Institute for Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IP	Internet Protocol
IS	Interim Standard
ISO	International Standards Organization
ITS	Intelligent Transportation Systems
JPEG	Joint Photographic Experts Group
JSTARS	Joint surveillance and target attack radar system
LAN	Local area network
LCD	Liquid crystal display

LPD	Low probability of detection
LPI	Low probability of intercept
MIPS	Millions of instructions per seconds
MPEG	Motion Picture Experts Group
NSF	National Science Foundation
OLE	Object Linking and Embedding
OMG	Object Management Group
OODBMS	Object-oriented database management systems
OSF	Open Software Foundation
OSI	Open Systems Interconnection
PCMCIA	Personal Computer Memory Card International Association
PDA	Personal digital assistant
POTS	Plain old telephone service
RDBMS	Relational database management system
R&D	Research and development
SEI	Software Engineering Institute
SMR	Specialized mobile radio
TAFIM	Technical Architecture for Information Management
TCP	Transmission Control Protocol
TRADOC	Training and Doctrine Command
TRM	Technical Reference Model
UDP	User datagram protocol
VLR	Visited Location Register
WACS	Wireless Access Communications System
WWW	World Wide Web

Executive Summary

The U.S. Army is currently pursuing its modernization vision, which recognizes that information and its effective use will be key to tomorrow's military victories. Future battlefields are slated to become large digital networks carrying vast amounts of information for real-time use by commanders and soldiers. The goal is to provide the right data, at the right place, at the right time. This study addresses the multimedia technologies that exist or are emerging in the civilian sector and could help the Army achieve its goal.

BACKGROUND AND APPROACH

Recognizing the potential of commercial multimedia technologies for Army use, the Deputy Assistant Secretary of the Army for Research and Technology asked the National Research Council to examine the applicability of such technologies to Army command, control, communications, and intelligence needs. The Committee on Future Technologies for Army Multimedia Communications was tasked to (1) review the Army's needs for echelons at the corps level and lower, (2) review relevant commercial multimedia technologies, (3) recommend technical approaches for meeting Army needs with commercial technologies, (4) describe the battlefield potential that might result from the application of multimedia technologies, and (5) recommend a technology management strategy by which the Army can use commercial multimedia technologies.

The committee focused initially on requirements as seen by the "customer"—in this case, the Army. It next reviewed relevant commercial technologies, from the perspective of status and trends. Each of these building block technologies and the Army's requirements were then brought together in a way that highlighted, for each technology, whether the Army should (a) adopt it off-the-shelf, (b) adapt it, or (c) pursue Army-specific development.

The committee examined how battle command in a typical Army corps combat operation might be affected by emerging multimedia information networking capabilities. The committee also reviewed macrolevel experiences in the private sector associated with applications of multimedia technologies. The resulting perspective formed the basis of committee projections concerning the need for the Army to "reinvent" itself in order to gain the full benefits of multimedia technologies. Finally, the committee laid out the essential elements of a technology management strategy for the Army.

The committee determined that the time frame of its study would extend approximately 15 years into the future (i.e., from 1995 to 2010). The earliest impact of the new multimedia technologies, beyond experimental and ad hoc applications, is expected to occur around the year 2000 as they are first deployed into operational units. The Army's Enterprise Strategy envisions widespread deployment of applications associated with digitization of the battlefield by the year 2010. The committee believes that multimedia information technologies and applications are evolving so rapidly that it is not realistic to project their nature and specific implications for Army battlefields more than a decade into the future. However, the committee also believes that its recommendations on technology management apply today and will continue to apply beyond the time frame of the study.

The remainder of this summary conveys the major findings that resulted from the committee's work and the principal conclusions and recommendations.

ARMY REQUIREMENTS

The Army has recognized the power of information and the technologies for handling and processing information on the battlefield. A smaller Army, based primarily in the United States and required to respond rapidly to worldwide contingencies, must have continuous access to accurate, current information. Commanders must be able to use information and protect it. Commanders at all echelons must have a shared, common understanding of real-time battlefield truth. Wrong information, misinformation, or disrupted access to information can be potentially disastrous. Army leaders and requirements documents put priorities on the following operational needs:

- *Improved Situational Awareness*. Situational awareness demands the accurate and timely (real-time) knowledge of friendly and enemy locations and status.

- *Common, Relevant Picture of the Battlefield*. All commanders, shooters, and supporters need to have the same understanding of the battlefield—locations, activities, capabilities, intent, terrain, and battlefield geometry—in the same relevant time frame.
- *Command On-the-Move*. Information must be available to the commander anywhere on the battlefield.
- *Improved Target Handoff*. There is a need for linking sensors and shooters through automated systems that reduce or eliminate lengthy, and often confusing, voice links.
- *Battle Space Expansion*. Commanders must be able to see and act throughout the depth, breadth, and height of the battlefield.
- *Information Protection*. Preventing the enemy from knowing what the friendly force knows and protecting friendly information systems from destruction, disruption, or manipulation are essential.
- *Exploit Modeling and Simulation*. In addition to the requirements for information distribution on the battlefield, Army leaders have emphasized an urgent need for the application of advanced simulation technology to support training, battle rehearsal, and the exploration of future concepts and materiel requirements.

The operational needs described above are summarized in Table ES-1. Table ES-1 also breaks out the major functional requirements that support each of the needs.

RELEVANT COMMERCIAL TECHNOLOGIES

The committee configured a generic layered architecture as a basis for identifying relevant building block technologies. This architecture is consistent with the DoD Technical Architecture for Information Management, with Army Science Board recommendations, and with the Common Operating Environment of the Army C^4I Technical Architecture. The committee's generic multimedia architecture is shown in Figure ES-1.

Naming of the various layers of the architecture explicitly reflects the fact that multimedia technologies are strongly dependent upon software. Layer I includes lightweight portable terminals, storage systems, and communications subsystems and systems to support people on the move. Layer II includes protocols for interconnecting subsystems, systems, networks and gateways, operating systems for managing computational resources, and distributed computing environments for managing distributed software processes. Layer III provides capabilities such as information filtering, database management, and user-friendly multimedia user interfaces. Layer IV provides generic applications/enablers such as multimedia teleconferencing capabilities and groupware, which can be tailored for Army-specific applications (e.g., simulation systems) residing on the top layer, Layer V. Woven throughout the architecture in what the committee considers to be a sixth "layer," Layer VI, are network management and security technologies.

TABLE ES-1 Summary of the Army Operational Needs, Including Simulation, and Functional Requirements

Army Operational Needs (Including Simulation)	Functional Requirements
Improved situational awareness	Sensors
Intercept capabilities	
Accurate position location	
Automated platform monitoring	
Interconnected communications networks	
Remotely accessed databases	
Decision support aids	
Scalable data	
Flexible graphics	
Common, relevant picture of the battlefield	Common distributed database
	Ability to access database
	Interconnected communications to transmit imagery, data, voice/ selective access
	"Eavesdrop" voice capability
	Portrayed graphically/scalable/easily understood
Command on-the-move	Reconfigurable software
	Common hardware, standards, protocols
	Rapid operation/turn-on
	Easily accessible networks
Improved target handoff	Linkage of sensors, computers, and communications
Battle space expansion	Satellite, fiber, wire, and long-range wireless communications
	Automated systems
Information protection	Nonjammable communications
	Nonpenetrable databases
	Unbreakable crypto and other security systems
Exploit modeling and simulation	Distributed interactive simulation
	Support exploration of future requirements

The relevant building block technologies, categorized according to the layers named above, are depicted in Figure ES-2. (Note that the building block technologies are numbered in the figure from bottom to top layers to indicate the order in which discussed in the report.) These technologies, and the capabilities they enable, are evolving rapidly under the pressure of commercial market forces and underlying technological advances. This bodes well for the availability of solutions from the commercial world to satisfy the Army's requirements.

Some examples of commercial system-level applications of these technologies include cellular and wireless telecommunications systems, electronic commerce, intelligent transportation systems, and residential information services. Cellular and wireless users are increasingly demanding more reliable and secure service with the ability to move around freely. In electronic commerce, network integrity, reliability, and security are major concerns. Applications of intelligent transportation systems include sending sensed traffic information to centralized nodes, distribution of traffic information to mobile travelers, location tracking and reporting, and map delivery systems for guiding travelers. Residential information services are striving to achieve user-friendly graphical (and other) user interfaces.

Lessons learned in the commercial world include the following:

- Creation of an effective communications and computing architecture requires that a few resonant minds create it, that they be given time to work, and that the architecture be enforced.
- With standards, enterprises can exploit their competitive advantages without having to be vertically integrated suppliers of end-to-end systems.
- Development efforts should be focused on areas where one intends to achieve a differentiating advantage over, competitors,[1] and everything else should be outsourced.
- Businesses tend to solve problems using as much off-the-shelf technology as possible; they meet the need and leave the detailed requirements flexible.
- The issue of "what to do with legacy systems" is growing in importance.
- The spiral model of development (i.e., quick iteration through requirements specification and respecification, prototyping, and testing) leads to substantially lower development costs, more rapid development, and substantially greater satisfaction of real user needs.

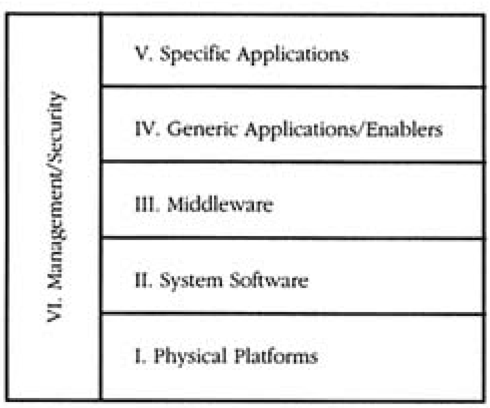

Figure ES-1
Generic architecture for multimedia communications.

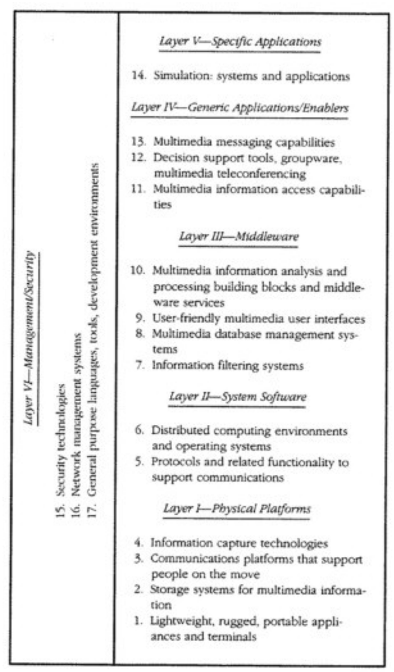

Figure ES-2
Building block technologies in the generic multimedia architecture.

[1] In the context of Army battlefields, "competitors" correspond to "potential adversaries."

These lessons, and others, provide support for the committee's later recommendations to the Army regarding the use of commercial multimedia technologies.

MEETING ARMY NEEDS WITH COMMERCIAL MULTIMEDIA TECHNOLOGIES

The committee mapped the commercial building block technologies onto the Army's operational needs and functional requirements. Table ES-2 summarizes this mapping; the building block technologies in Table ES-2 are numbered according to Figure ES-2. Note that most of the needs and requirements require a combination of two or more of the building block technologies. Also, most of the building block technologies can be used to satisfy multiple needs and requirements. Thus, common technologies can be leveraged across the array of needs. An open architecture facilitates such leveraging and provides a means to insert new technologies rapidly.

The committee proceeded to make recommendations for each building block technology according to the following designators:

- The designator C indicates that the commercial market pull is so great that industry will develop this technology faster than the Army could. The Army should adopt these technologies off-the-shelf to meet its needs because it will not likely be able to create a competitive advantage by pursuing Army-specific development.
- The designator M indicates that the committee recommends the Army modify or adapt commercial technologies to meet its requirements. Where this is the case, it is advisable that the Army consider its requirements with a view toward commercial product availability.
- The designator A indicates that the technology is one in which the Army should invest. In this case the committee believes that the Army requirements are unique and that industry will not develop this technology on the time scale the Army needs. Furthermore, the Army has a reasonable opportunity to develop a competitive advantage vis-a-vis its adversaries by investing in these technologies. This competitive advantage will likely result from developing an enabling technology which more effectively leverages commercial off-the-shelf technologies in battlefield applications.

Because each building block technology may meet some Army requirements, but not others, the committee has also recommended a combination of C, M, or A in some cases. A summary of the committee recommendations is given in Table ES-3.

With reference to Table ES-3, the recommended Army investment is heavily focused at the bottom layer and top layer of the architecture and on security technology in Layer VI. For the most part, the middle-layer technologies should be acquired through commercial sources. With respect to security concerns, isolating Army-specific security requirements by using standard interfaces between security functionalites and the building blocks in Layers II-IV will best allow the Army to keep up as commercial building block technologies evolve.

A recurring observation was that the Army should use commercial off-the-shelf technology wherever possible, even to the extent of redefining requirements to do so. To support this recommendation, the committee argued that most estimates of the size of the emerging commercial multimedia market for technologies, services, and applications range from 10 to 20 percent of the gross domestic product of developed countries. This enormous market, whose applications are in many ways similar to Army applications, creates a correspondingly enormous market pull for the creation of technologies by commercial suppliers. The Army can achieve maximum competitive advantage over its adversaries in the same way that commercial firms achieve market advantage•by focusing on applying these technologies as quickly as possible in battlefield applications, rather than by competing in the creation of the underlying technologies themselves. Furthermore, when the Army does invest in research and development to create technologies other than applications to meet unique Army requirements, the principal purpose in doing so should be to produce physical platforms, communications capabilities, and security and network management functionality that will enable the Army to adapt commercial off-the-shelf technologies to Army applications. These adaptations result from stringent military requirements for such things as anti-jam radio characteristics or resistance to electromagnetic pulse.

The committee did note a few exceptions to the above in technologies such as automatic pattern recognition for image analysis, and large-scale distributed simulation, where the Army has requirements that are more compelling than those in commercial applications.

By means of an operational example, it became clear to the committee that application by the Army of the information technologies discussed above can have far-reaching effects. While the activities are nominally the same—whether supported by automated systems and multimedia communications or by manual systems and messengers—there are many differences. These are the speed and accuracy of information distribution, continuous and automatic update of databases, simultaneous informing of all involved, and freedom of commanders and staffs from repetitive tasks. The effect on unit organizational structure and tactics could be dramatic.

TABLE ES-2 Summary of Army Operational Needs, Including Simulation, and Functional Requirements and Their Most Relevant Enabling Building Block Technologies

Army Operational Needs (Including Simulation)	Functional Requirements	Building Block Technologies[a]
A. Improved situational awareness	A1 Sensors	4
A2 Intercept capabilities	4,10	
A3 Accurate position location	4,10	
A4 Automated platform monitoring	4,10	
A5 Interconnected communications networks	3,5,16	
A6 Remotely accessed databases	2,3,5,6,7,8,11,16	
A7 Decision support aids	10,12	
A8 Scalable data	2,7,10,11	
A9 Flexible graphics	9	
B. Common, relevant picture of the battlefield	B1 Common distributed database	2,3,5,6,8
	B2 Ability to access database	2,3,5,6,11,15,16
	B3 Interconnected communications to transmit imagery, data, voice/selective access	3,5,11,13,15,16
	B4 "Eavesdrop" voice capability	3,5,11,12,15
	B5 Portrayed graphically/scalable/easily understood	8,9
C. Command on-the-move	C1 Reconfigurable software	6,17
	C2 Common hardware standards, protocols	1,3,5,6,17
	C3 Rapid operation/turn-on	1,3,5,6
	C4 Easily accessible networks	3,5
D. Improved target handoff	D1 Linkage of sensors, computers and communications	3,4,5,6
E. Battle space expansion	E1 Satellite, fiber, wire, and long-range wireless communications	3,5
	E2 Automated systems	2,7,8,9,10,11,12,13
F. Information protection	F1 Nonjammable communications	3,15,16
	F2 Nonpenetrable databases	2,15
	F3 Unbreakable crypto and other security systems	15
G. Exploit modeling and simulation	G1 Distributed interactive simulations	All
	G2 Support exploration of future requirements	All

[a] There are 17 technologies, represented here by number. The list of 17 appears in Figure ES-2.

Smaller forces, widely separated, will be able to operate simultaneously and at a vastly increased pace and tempo. Ammunition and logistics stockage levels can probably be reduced as support units maintain a real-time accurate knowledge of each unit's status and deliver the needed supplies on time and without requests. Smaller staffs employing automated systems and support aids will be able to coordinate the operations of more subordinate formations and provide more accurate and more timely support to commanders.

The scenario implies an information architecture where data are a corporate resource shared by many applications. The technology challenges in this regard lie

TABLE ES-3 Recommendations for Commercial, Modified, or Army-Specific Products in Each of the Building Block Technology Areas

Architecture Layer[a]	Building Block Technology	C Commercial	M Modified	A Army-Specific
I	1. Lightweight, rugged, portable appliances and terminals	**X**	X	
I	2. Storage systems for multimedia information	**X**	X	
I	3. Communications platforms that support people on the move	**X**	X	X
I	4. Information capture technologies	**X**	X	X
II	5. Protocols and related functionality to support communications	**X**		
II	6. Distributed computing environments and operating systems	**X**		
III	7. Information filtering systems	**X**		X
III	8. Multimedia database management systems	**X**		
III	9. User-friendly multimedia user interfaces	**X**	X	
III	10. Multimedia information analysis and processing building blocks and middleware services	**X**		
IV	11. Multimedia information access capabilities	**X**		
IV	12. Decision support tools, groupware, multimedia teleconferencing	**X**		
IV	13. Multimedia messaging capabilities	**X**		
V	14. Simulation: systems and applications	**X**	X	X
VI	15. Security technologies	**X**		X
VI	16. Network management systems	**X**	X	
VI	17. General purpose languages, tools, development environments	**X**		

[a] Layers I-VI are depicted in Figure ES-2.

in transitioning legacy systems; building open and distributed computing environments that are secure and reliable; and provisioning and managing the capacity of information servers, processing resources, and communications. These are major challenges that will be addressed mostly by commercial technology trends. The Army should monitor these trends and adopt the best commercial practices. Even in the case of security, some commercial encryption schemes might be acceptable, although the Army will have to influence commercial trends to accommodate any unique requirements.

REINVENTION IN THE INFORMATION AGE

The changing business environment coupled with accelerated technological introductions have made no corporation exempt from re-examining the basics of its business. However, successful corporate change seldom results from technology alone—the nature of the work and the structure of the organization usually change as well.

Three successful corporate reinvention cases considered relevant to the Army were discussed in detail:

- Citicorp brought the workstation environment and corporate information to virtually every employee with large productivity gains. Citicorp also has been restructuring its business, outsourcing more non-critical business functions, and dramatically downsizing its work force.
- Federal Express successfully implemented an enterprise-wide tracking and monitoring system for its packages, which stemmed from the realization that knowing the location of a package was as important as the shipment itself. The Federal Express story underscored the need for iterative design and development.
- The Ford Motor Corporation made a significant turn-around in the 1980s. Much of its success can be attributed to continuous quality improvements and participatory management techniques. Ford's redesign of its accounts payable department is frequently cited as a reengineering success story.

Only about one in four reengineering projects succeeds. Among the many ways they fail are (a) attempting to reengineer processes or business functions that are better left alone; (b) not starting small and building from success; (c) not having the critical skill sets available; and (d) not being able to change the culture to accommodate reengineering. The rapid evolution of information technologies and the application of information technologies in Army battlefields have implications that can be inferred from these commercial corporate reinvention experiences. The Army will need to change its organization, doctrine, and tactics. It will need to actively experiment with new organizational structures, doctrine, and tactics, and it will need to iteratively design and develop systems that derive maximum impact from information technologies.

It is wrong to believe that just the technologies will change. The Army will have to analyze the role and functions of unit staffs in the information age and the purpose served by each level of command, with an eye to the following:

- Processes and work flow in unit staffs will change. They can be smaller and are likely to be restructured around the functions that must be performed.
- It may be possible to eliminate one or more levels of command. Flatter, more integrated, and less vertical entities will evolve. Intervening levels between the decision maker and executor will become redundant and an impediment to efficient operations.
- Operations can take place faster and be synchronized over a wide area. The implications for Army doctrine and tactics are likely to be extensive. While the effects are not yet fully evident, corporate experience indicates that those who fail to reassess the fundamental way business is conducted and adjust to newly enabled ways will not leverage the advantages of information technologies.
- Success is made with plans of limited scope that are intended to be built, tested, redesigned, and expanded. Digitizing the battlefield will require much experimentation and refinement. Thus, Army battle laboratories will become even more critical and probably expanded in coming years.

TECHNOLOGY MANAGEMENT STRATEGY

The key elements of a technology management strategy by which the Army can leverage multimedia information technologies for battlefield applications are described below. Although some of what follows may echo familiar themes, the committee wants to reiterate them to (a) accelerate their implementation, (b) provide support in the context of applying multimedia information technologies, and (c) emphasize its concern that they are not being implemented aggressively enough. In particular, the committee believes that these recommendations are specifically relevant to multimedia information technologies and applications because of the very short time scales within which these technologies evolve and because of the widespread application of these technologies in commercial domains.

The technology management strategy consists of eight primary recommendations. The recommendations follow in boldface type:

RECOMMENDATION 1: The Army should be a hunter-gatherer of technologies, seeking out and acquiring the best technologies wherever it can find them, to meet overall strategic objectives, and applying them in an opportunistic manner to meet battlefield demands. The Army should leverage commercial off-the-shelf technology (i.e., design applications and systems that can utilize such technology rather than setting objectives and requirements that require the invention of nonexistent technology). The Army should not compete with the commercial sector in developing generically applicable technology.

RECOMMENDATION 2: The Army should carefully distinguish between: (a) those technologies that are emerging and evolving in the commercial marketplace and will be available to everyone, including the Army's adversaries, and (b) those technologies that the Army can reasonably expect to create as competitive enablers to differentiate the Army from its adversaries. For those technologies that fall in the former category, the Army should focus on their expedited and innovative use in battlefield applications. For those technologies that fall into the latter category, the Army should invest in Army-proprietary research and development efforts to achieve the desired differentiating advantages. Recommendations for specific building block technologies are summarized in Table ES-3.

RECOMMENDATION 3: The Army must achieve a better balance in its procurement processes between the imperative to make these processes fair and competitive and the imperative to effectively acquire, insert, and deploy information technologies whose life cycles can be as low as 18 months. Specifically, the Army must recognize the iterative interaction between requirements and what is technically feasible.

RECOMMENDATION 4: The Army should create and enforce a technical architecture. That architecture should (a) promote reuse of building block technologies across multiple systems, interoperability between systems, and expedited insertion of new technologies to achieve cost reductions and performance improvements; and (b) facilitate ad hoc modifications of systems and applications to meet short-term needs in crisis situations.

RECOMMENDATION 5: The Army should be an active participant in technology development in the commercial sector. The Army should access information regarding commercial technology trends, influence commercial technology trends to accommodate Army-specific requirements, and proactively endeavor to benefit from commercial experiences and innovations in the application of technology. To accomplish this, the Army should act in the role of a leading-edge customer providing commercial firms access to its needs. It should actively participate in standards activities. The Army should continue to participate in internal and external research and development activities directed toward its unique requirements.

RECOMMENDATION 6: The Army should respond to the need for reinvention. It should expect that rapid advances in communications and computational capabilities resulting from trends in commercial multimedia technologies will result in more than quantitative improvement in the ability of soldiers and commanders to execute existing command and control paradigms. It is likely that the Army will have to reinvent its organizations, doctrines, and tactics related to command and control to leverage these rapidly evolving technologies and to remain competitive with its adversaries.

RECOMMENDATION 7: The Army must adopt a spiral model of development where the iterative specification of requirements, prototyping, testing by users, and refinement/respecification of requirements proceeds in periods measured *in months* to create new systems and applications. This process must make heavy use of simulation, modeling, and experimentation in order to achieve the desired iteration speeds and to achieve realistic prototyping and desired user feedback.

RECOMMENDATION 8: The Army should create and adopt a qualitative index to measure progress made toward achieving its technology management goals. A Commercial Technology and Practices Index consisting of four levels was developed by the committee as an example.

1—

Introduction

This chapter discusses the background that led to this study, including a snapshot of the multimedia communications problems facing the Army. It also sets forth the statement of task and describes the way in which the committee carried out the task.

BACKGROUND

The U.S. Army is currently pursuing its modernization vision for the Army of the late 1990s and the next century. The vision recognizes that information and its effective use will be key to tomorrow's military victories. Specifically, the Army will have to gather, transmit, process, and distribute information on friendly and enemy forces while at the same time denying the enemy similar capabilities.

Under Army modernization initiatives, future battlefields are slated to become large digital networks. These networks will carry vast numbers of information packets at high speeds from sources such as sensors and processors to commanders and soldiers. This information will be shared in near-real-time by Army units throughout the operational zone. One end result will be a common view of the battlefield, to include continuously updated locations of friendly and enemy forces.

The digital sensors and processors will create an explosion of information that must be integrated and communicated almost instantaneously if it is to be useful. The goal is to provide the right data, at the right place, at the right time. However, melding, screening, and disseminating huge quantities of digital information among friendly units engaged in battle are not within the U.S. Army's current capability.

Commercial multimedia information technologies, which exist and are emerging in the civilian sector, could help the Army develop such information-handling capabilities. These technologies could be considered for application throughout all echelons of the battlefield.

STATEMENT OF TASK

Recognizing the information management and communications problems and opportunities facing the Army, and the potential use of commercial multimedia technologies to assist in their solution, the Deputy Assistant Secretary of the Army for Research and Technology asked that the National Research Council conduct a study. The study would examine the applicability of commercial multimedia communications to Army command, control, communications, and intelligence (C^3I) needs. For the purposes of this study, multimedia communications means the capture, transport,[1] storage, processing, delivery, and presentation of information consisting of digital representations of combinations of text, sound, images, video, and data structures for applications in real-time collaborative work, messaging, and access to information. This interpretation of the terminology "multimedia communications" was based on discussions between the chairman of the committee and the sponsor of the study prior to the commencement of the study.

The statement of task for the study was established as follows:

- Review the Army's current and projected functional requirements (mission requirements) for C^3I for echelons at the corps level and lower.
- Gather information through such means as literature reviews and workshops to ascertain relevant multimedia hardware and software technologies that are currently available, or likely to be developed, for commercial applications.
- Based on these reviews of Army requirements and commercial multimedia technologies, recommend technical approaches for meeting the Army's current and projected C^3I needs at the corps level and lower with systems based on technologies originally developed for commercial markets. Technical approaches may include, among other things, direct use of commercial products, adaptation of products or production methods, and cooperative efforts.
- Describe potential battlefield capabilities, advanced concepts, or operational impacts that might result from application of advanced communications and that are not reflected in current or projected Army C^3I requirements.

[1] The word "transport," as used above, refers to the movement of information through transmission paths (e.g., radio or fiber), switches, and other equipment to allow geographically separated entities to exchange information with each other.

- Recommend a tecnology management strategy by which the Army can most successfully use or adapt commercial multimedia technologies for Army C^3I applications. Elements of such a strategy may include, among other things, requirements definition, simulation, test and evaluation methodologies, acquisition, and fielding.

STUDY APPROACH

The committee focused initially on requirements as articulated from the point of view of those who would apply technologies, embodied in systems and applications, both in battlefields and in operations other than war. This represented a "customer" perspective that focused on the anticipated benefits of the technology, rather than the technology itself. Senior Army officers and other Army personnel discussed C^3I needs and systems currently in use. In addition, the committee reviewed numerous documents that expressed Army C^3I needs. The results are summarized in Chapter 2, which represents a customer-driven articulation of requirements. Next came the points of view from representative commercial suppliers of technology that could be used to satisfy the customer's needs. The committee reviewed the status of and trends associated with key multimedia communications technologies, drawing on invited presenters and its own experts. The committee configured a generic layered architecture as a basis for identifying building block technologies needed to meet Army requirements. Summaries of these building block technologies, as well as some commercial applications and important lessons learned, are found in Chapter 3.[2]

Chapter 4 contains recommendations from the committee regarding the applicability of existing and evolving commercial multimedia technologies to Army needs. To create these recommendations, the committee proceeded as follows:

- The committee combined the needs of the Army, as articulated in Chapter 2, with its understandings of commercial multimedia building block technology capabilities and trends developed in Chapter 3.
- The committee assessed the likelihood that commercially driven advances in each of these building block technologies would occur faster than any reasonable levels of Army-specific development.
- The committee also assessed requirements that would be unique to the Army, that is, needs that the Army would have that might not be met by technologies driven by large commercial markets.
- From these assessments, the committee judged whether the Army should (a) adopt commercial off-the-shelf technology, (b) adapt commercial off-the-shelf technology, or (c) pursue Army-specific development to meet its unique needs.
- The net result was a set of recommendations about how the Army should acquire multimedia technologies and a strategy for meeting its requirements.

In Chapter 4 the committee also examined how battle command in a typical Army corps combat operation might be affected by the multimedia capabilities enabled by the building block technologies. The chapter concludes with an analysis of the prognosis for realization of the capabilities in the operational example.

In Chapter 5 the committee reviewed macro-level experiences that have been obtained from applications of multimedia technologies in the private sector (e.g., financial institutions). This review offered perspective with respect to both the use of these technologies and overarching lessons learned regarding how to successfully incorporate them into large, information-intensive organizations. This perspective formed the basis of committee discussions concerning the need for the Army to "reinvent" itself in order to gain the full benefits of the use of multimedia technologies. Specifically, the committee considered changes at the corps level and below that go beyond quantitative improvements in the ability to acquire, process, and communicate information. For example, changes in organization, doctrine, and tactics may occur.

Chapter 6 addresses a strategy for technology management. The chapter contains recommendations specifically targeted to the leaders, administrators, and managers in the Army who will lead the transition from today's Army to the Army of the future. While some of these recommendations have appeared elsewhere, the committee wants to add its weight to them. These thoughts derive both from the preceding chapters and the considerable expertise of the members of the committee in the application of commercial information technologies. Finally, Chapter 7 is a compilation of the committee's conclusions and recommendations resulting from this study.

[2] The committee concentrated on building block technologies that were selected on the basis of a generic layered architecture. The building blocks ranged from lightweight, hand-held appliances to generic enabling applications like multimedia information filtering but excluded device technologies like microchips. These building block technologies allow one to do things such as capture, store, move, and recall information (i.e., they are application focused).

The committee determined that the time frame of its study would extend approximately 15 years into the future (i.e., from 1995 to 2010). The earliest impact of the new multimedia technologies, beyond experimental and ad hoc applications, is expected to occur around the year 2000 as they are first deployed into operational units. The Army Enterprise Strategy[3] envisions widespread deployment of applications associated with digitization of the battlefield by the year 2010. The committee believes that multimedia information technologies and applications are evolving so rapidly that it is not realistic to project their nature and specific implications for Army battlefields more than a decade into the future. However, the committee also believes that its recommendations on technology management apply today and will continue to apply beyond the time frame of the study.

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Department of the Army. 1993. Army Enterprise Strategy—The Vision. July 20.

[3] The Army Enterprise Strategy is the single, unified vision for the Army command, control, communications, computers, and intelligence community. The document that describes this vision "outlines the strategy and the principles by which we will exploit current and future information technologies, adopting new systems and using executive decision making as a means to advance the capability of the Total Army Force." (Department of the Army, 1993)

2—

Review of Army Requirements

This chapter reviews the Army's operational needs and functional requirements as they relate to the application of technologies to enhance the use of information by battlefield commanders and their staffs.

"FORCE XXI … Build the Army around information."

—General Gordon R. Sullivan, Chief of Staff, U.S. Army (Sullivan, 1994)

MILESTONE— DESERT STORM

The Persian Gulf War, where the United States marshaled world opinion and led an international coalition to defeat Iraqi forces and force their withdrawal from Kuwait in Operations Desert Shield/Desert Storm, marked a historic milestone in several respects. U.S. and Russian cooperation and the international response to Iraqi aggression made it clear that the bipolar, Cold War era was over. More importantly, from the standpoint of this study and the evolution of modern warfare and military technology, the Gulf War could be described as the first war of the information age. It provided a sharp glimpse of the potential advantage to be gained by military forces that can harness modern technologies for the control of information on the battlefield.

With the end of the Cold War, U.S. military and civilian leaders began a review of potential threats to national security and how to respond to them. The resulting new National Military Strategy envisions smaller military forces capable of rapid force projection from the continental United States and forward deployed locations. Force levels are to be maintained at sufficient strength to deal with two regional contingencies nearly simultaneously.

ARMY MODERNIZATION PROGRAM

In keeping with the new strategy, the U.S. Army has reduced its war fighting strength by about 30 percent over the past three years. It has eliminated one corps, eight active and two reserve component divisions, and several smaller units, with further reductions programmed. [1] At the same time, in spite of budget reductions, the Army has pursued a modernization plan intended to maintain a technological edge over any potential enemy. In the words of the Secretary of the Army, the Honorable Togo D. West, Jr., and the Chief of Staff of the Army, General Gordon R. Sullivan (in their joint cover letter to the Army Modernization Plan (Department of the Army, 1994c)), "America's Army must respond to the crises of today and tomorrow … with such overwhelming, technically superior force as to render any potential adversary impotent and minimize our cost in soldiers' lives."

The Army, as an institution, has recognized the power of information and the technologies for handling and processing information on the battlefield to achieve overwhelming superiority. There is universal agreement within the Army's leadership that the power of information was perhaps the key lesson to be learned from the Gulf War. Neither has that lesson been lost on potential adversaries.[2] If the U.S. Army is deployed in a future regional conflict, it can expect the enemy to employ modern communications and information technologies in support of enemy battlefield operations. The United States will need better systems and information to prevail. Given the speed with which such technologies are advancing, if the U.S. technological advantage is lost, it will be very difficult to regain. With a smaller, post-Cold War force, the Army has placed a high priority on

[1] The following coarse definitions of various Army units were used by the committee during this study, which focused on echelons at the corps level and lower. A corps is a large fighting unit that typically consists of two or more divisions plus supporting arms and logistical service units. Its strength can vary widely, depending upon the mission and units assigned to the corps. There are several types of divisions ranging in size from about 10,000 soldiers (Light Infantry Division) to about 18,000 soldiers (Armored and Mechanized Infantry Divisions). Three brigades, each in the range of 3,000 to 5,000 soldiers, normally make up a division. Several battalions (up to 1,000 soldiers each) make up a brigade. Approximately three to five companies of about 100 to 150 soldiers each normally make up a battalion. Several platoons (around 40 soldiers each) make up a company. The platoon is made up of several of the smallest units, known as squads, which have about 10 soldiers each.

[2] Modern communications and information technologies are available to any Third World nation with the money and the will to purchase them on the commercial market. Other nations are already adopting such technologies to their military requirements. For example, commercial satellites are available for communications, position location, data distribution, and imagery.

maintaining, and indeed improving, its advantage in applying information technology to achieve battlefield success.

To accomplish the new National Military Strategy in the information age, the Army has a modernization vision designed to ensure the retention of Land Force Dominance. The Army has defined several modernization objectives essential to achieving this vision:

- Project and sustain army forces;
- Protect the force;
- Win the information war;
- Conduct precision strikes against enemy forces; and
- Dominate the maneuver battle.

While no one of these objectives is more important than the others, winning the information war has implications for all the others.

WINNING THE INFORMATION WAR

Winning the information war has three essential components: (1) effective use of information by friendly forces, (2) protection of friendly information from the enemy, and (3) attack against enemy information and information systems.[3] The third component involves actions by friendly forces to destroy, degrade, or spoof the enemy's information, as well as the covert penetration of enemy information systems to know what the enemy knows. This third component is not within the scope of this study. Therefore, the discussion below considers only the first two components.

The first component, effective use of information by friendly forces, entails the gathering, processing, transmission, dissemination, and display of battlefield information accurately, efficiently, and in a timely manner. The second component, protection of friendly information, entails preventing the enemy from (a) knowing what the friendly force knows; (b) gaining accurate information about friendly force locations, activities, status, or intentions; and (c) destroying or modifying information in friendly databases or disrupting communications or access to data.

Army statements of requirements and the emphasis in most of its internal combat and materiel development communities have focused on improving the effective use of information by battlefield commanders. The Army's experiments, field exercises, and technology demonstrations have placed a priority on improved battle command, which combines the art of deciding, leading, and motivating by commanders in battle with the means of communicating a commander's decisions and intent to soldiers and their leaders in order to achieve mission success. Also, recognizing the importance of protecting information, the Army has consistently stated the need for secure, nonjammable communications and the protection of automated systems from penetration, manipulation, or the introduction of computer viruses.

Army Battle Command Priorities

The Army's concept of future battle and the key role of battle command on future battlefields are articulated in the Training and Doctrine Command's Pamphlet 525-5 (Army TRADOC, 1994). The vision of future battle command is reflected in the Army Battle Command Systems (Army Training and Doctrine Command, 1993). Both documents, along with the information provided to the committee by Army briefers, offer broad statements of Army requirements for battlefield communications and information distribution. All the sources available to the committee have placed emphasis on the application of technologies to enhance the use of information by commanders and staffs, under the unique conditions of the battlefield, to achieve a decisive advantage over the enemy. Repeatedly, Army leaders and requirements documents put the Army's priorities for the application of information technologies on the following operational needs.

Improved Situational Awareness

Situational awareness demands the accurate and timely (near-real-time) knowledge of friendly and enemy locations and status. Locations of friendly platforms and units are most important to avoid fratricide, to improve coordination, and to focus unity of effort on the overall mission. Information on friendly unit status should be scalable by echelon and must be sufficient for the relevant commander to judge the ability of subordinate organizations to accomplish the mission. Enemy information is needed both for intelligence and targeting. Commanders need to know where enemy forces are and their capabilities and intentions, so judgments can be made about the ability of the enemy to interfere with the friendly unit mission and about which enemy formations should be attacked and when. Shooters need to know enemy locations with sufficient precision and timeliness to ensure successful engagement.

[3] General references for this section are Army Combined Arms Center, 1994; Department of the Army, 1993a; Department of the Army, 1993b; Department of the Army, 1994a; and Department of the Army, 1994b.

This requirement implies the need for sensors to detect and track the enemy; intercept capabilities to learn what the enemy knows and his intentions; accurate position location and automated monitoring of friendly platforms and units; interconnected communications networks to carry data, images, and voice wherever needed; a database that can be accessed from remote locations, provides "rolled up" data that are suitable and scalable to each echelon, and also permits selective shredding or de-aggregation of data to the lowest level; flexible, easily understood graphics that can be readily manipulated; and decision support aids to assist commanders in analyzing information and assessing alternative courses of action. To avoid information overload, particularly at the lowest levels, it is important for commanders at each echelon to be able to filter the data so they receive only the relevant information and to adjust the filters as requirements change.

Common, Relevant Picture of the Battlefield

All commanders, shooters, and supporters need to have the same understanding of the battlefield—locations, activities, capabilities, intent, terrain, and battlefield geometry—in the same relevant time frame. Commanders need to be able to describe the mission and explain their intent to their subordinates in real time so it is accurately understood by all.

The implications of this requirement are: the need for a common distributed database; the ability to access the database from anywhere on the battlefield; the need for interconnected communications networks with the capability to transmit up-to-date imagery, data, and voice and permit the selective access to data as it is broadcast; and the ability to "eavesdrop" voice communications in subordinate and adjacent units. The information must be able to be portrayed graphically, organized to meet the needs of individual commanders, filtered and scalable to each echelon, readily "pulled" from the relevant database (wherever it may reside), and displayed so the relevant information is clearly visible and understood.

Command On-the-Move

Information must be available to the commander anywhere on the battlefield. Command presence is an essential element of a commander's ability to lead and motivate. It is also essential for the commander to see and hear for himself what is happening on the battlefield. Some information and communications capabilities must be available under all circumstances, regardless of the mode of travel. Commanders must be able to access the full capability of the battle command system quickly, from any node, anywhere on the battlefield during brief halts and at subordinate or adjacent unit locations. This implies the need for reconfigurable software;[4] common hardware, standards, and protocols; communications and information systems that can be quickly put into operation; and easily accessible communications networks that overlay the entire battlefield.

Improved Target Handoff

Improved situational awareness and the common picture of the battlefield are essential to improving target handoff procedures. There is a need for linking sensors and shooters through automated systems that reduce or eliminate lengthy, and often confusing, voice links. Human involvement through the establishment of priorities and criteria for engagement, initiation procedures, or override capability will be required, but linking sensors with relevant computers and communications will improve the accuracy and timeliness of targeting data and permit the automated transfer of the target from a detection sensor or another shooter for rapid, precise engagement. For example, the linkage of the tank laser range finder with an on-board computer, position location device, turret orientation sensor, and digital radio would permit the accurate transfer of a target from the tank commander to another tank, an Apache helicopter, or the direct support artillery by simply touching a fire request prompt on the screen display.

Battle Space Expansion

Commanders must be able to see and act throughout the depth, breadth, and height of the battlefield. The application of overwhelming combat power no longer requires the employment of large massed formations, or even the delivery of massive, sustained fires. Simultaneous attack of key targets and enemy formations throughout the battlefield coupled with rapid, unexpected deep maneuver confuses the enemy, then paralyzes him, and finally creates panic, fear, and disintegration, resulting in the defeat of even unengaged forces. Information technology offers the means to expand the battle space by enabling rapid transmission and distribution of sensor data and intelligence so that the commander can see all

[4] Reconfigurable software provides an ability to change functionality rapidly anywhere on the battlefield without affecting the communications network. It should be possible to convert workstations on the battlefield to perform different automated functions by simply loading the appropriate software.

of the battlefield, know more than the enemy knows, and accurately target and attack the enemy while controlling his own forces with precision. The expanded battlefield implies the need for a combination of satellite, fiber, wire, and long-range wireless data communication networks and automated systems that work together to gather, sort, assemble, transmit, and display the information obtained where and when it is needed.

Information Protection

Preventing the enemy from knowing what the friendly force knows and protecting friendly information systems from destruction, disruption, or manipulation are essential to maintaining an accurate picture of the battlefield and up-to-date situational awareness. To provide such protection requires nonjammable communications, non-penetrable databases, and unbreakable cryptographic and other security systems.

Exploit Modeling and Simulation

Although models, simulators, and simulations might not be classified as "operational needs" in the purest sense of operational requirements for battle command, their application can aid significantly in battle preparation and analysis.

In addition to the requirements for information distribution on the battlefield to support Army battle command, Army leaders have emphasized an urgent need for the application of advanced simulation technology to support training, battle rehearsal, and the exploration of future concepts and materiel requirements. The Army envisions a distributed interactive simulation environment that would permit linking live field operations (soldiers employing organic equipment) with virtual reality environments (manned simulators) and constructive simulations (computer-driven, with or without human interaction). Organic electronic equipment (radios, telecommunications, displays, sensors, automated command and control systems, etc.) can be employed within this synthetic environment to permit soldiers and units to train or rehearse battle plans as they intend to fight. The environment also permits the realistic operational employment of systems and units for the evaluation of advanced doctrinal concepts, future organizations, materiel requirements, and the testing and evaluation of developmental equipment. A detailed description of distributed interactive simulation is contained in a Modernization Plan (Department of the Army, 1994c) and an investment strategy (Department of the Army, 1994d). The distributed interactive simulation environment is intended to overlay the Army's organizational structure permitting widely separated units to train together, to rehearse battle plans prior to execution, to evaluate completed missions, to explore future concepts, and to test and evaluate materiel during the research, development, and acquisition cycle.

The six operational needs, along with the seventh need to exploit modeling and simulation technology, are summarized in Table 2-1. Table 2-1 breaks out the major functional requirements that support each need.

TABLE 2-1 Summary of the Army Operational Needs, Including Simulation, and Functional Requirements

Army Operational Needs (Including Simulation)	Functional Requirements
Improved situational awareness	Sensors
Intercept capabilities	
Accurate position location	
Automated platform monitoring	
Interconnected communications networks	
Remotely accessed databases	
Decision support aids	
Scalable data	
Flexible graphics	
Common, relevant picture of the battlefield	Common distributed database
	Ability to access database
	Interconnected communications to transmit imagery, data, voice/ selective access
	"Eavesdrop" voice capability
	Portrayed graphically/scalable/easily understood
Command on-the-move	Reconfigurable software
	Common hardware, standards, protocols
	Rapid operation/turn-on
	Easily accessible networks
Improved target handoff	Linkage of sensors, computers, and communications
Battle space expansion	Satellite, fiber, wire, and long-range wireless communications
	Automated systems
Information protection	Nonjammable communications
	Nonpenetrable databases
	Unbreakable crypto and other security systems
Exploit modeling and simulation	Distributed interactive simulation
	Support exploration of future requirements

Additional Insights

After reviewing the various briefings and documents that outline the Army's requirements for future battle command, a member of the committee arranged interviews with several Army leaders.[5] The purpose of these interviews was to verify what the committee had learned and to seek further insights into the Army's concepts for the application of information technologies.

There was a generally consistent thread that ran through all of these individual discussions. All of the Army leaders emphasized the importance of "digitizing the battlefield" in order to take advantage of the potential afforded by modern information technology, and all identified the same broad requirements as articulated in the briefings and documents available to the committee. In addition, the discussions also provided a sharper view of some important considerations associated with achieving the Army's future battle command concept. These considerations are addressed below.

Improved Acquisition. Some frustration was expressed regarding the time it takes to progress from requirements to a fielded product. The speed with which microelectronic and information processing technologies are advancing almost guarantees that a deliberate development and procurement process using current procedures will lead to the fielding of obsolescent systems. The Army must be able to adopt and adapt commercial off-the-shelf technology to its needs. However, the application of some subsets of commercial technology, particularly hardware and wireless communication technologies, will be most difficult at brigade level and below. The battlefield environment and the basic tasks and missions to be performed at these levels present difficult Army-specific challenges, and commercial, off-the-shelf technology is in some cases not well suited to these requirements.

Information Filtering. Intelligence data, and situation reports, and other kinds of essential information must be "pushed" so that they are available to all locations and levels. An adjustable information filtering capability would ensure that relevant information is passed where needed and that commanders would be able to "pull" additional information when needed.

Battlefield Data Transmission. The Army needs an improved multimode, multiband battlefield information transport system at reasonable cost that can be proliferated in quantity to the lowest levels.

Displays. Emphasis should be placed on providing user-friendly, easily operated displays that do not distract the commanders or operators from their primary combat functions. Displays must assist the commanders in accomplishing the mission; this is particularly important for those systems provided at the lowest (platform) level where leaders and crew members must focus their full sensory perceptions on the battlefield around them. Next in importance are scalable data—the ability to roll data up and then de-aggregate it, integrate it with useful graphics, and present it in an easily understood display.

Operations Other than War

It is important to note that the Army requirements outlined in this chapter have been derived primarily from the vision behind creating the digital battlefield for Force XXI.[6] Information technologies designed to satisfy these Army requirements must operate on Army-specific infrastructure in a battlefield environment. These same technologies must be easily portable to indigenous infrastructure, where such infrastructure exists, during contingency deployments or operations other than war. The technologies and the architecture for applying them to Army requirements must include well defined interfaces for modular, flexible, and reusable systems that will allow for applications to Army-specific infrastructure as well as to indigenous infrastructure when available.

A Word of Caution

Developing and providing the systems and networks to meet the Army's vision of future battle command demand a word of caution, particularly with regard to meeting the requirements for a shared, common understanding of real-time battlefield truth. It will be important for the automated processes that manipulate the information to be visible and understood by those who use

[5] General Wishart interviewed the following persons: Major General Joe Rigby, Director, Army Digitization Office, on October 11, 1994; Brigadier General Joe Oder, Director of Requirements, Office of Deputy Chief of Staff for Operations and Plans, on October 13, 1994; General Frederick Franks, Commander, Training and Doctrine Command, on October 17, 1994. On January 4, 1995, a small group of committee members met with the Chief of Staff, General Gordon R. Sullivan, and on March 20–21, 1995, a group of six committee members visited the facilities and ranges at Fort Hood, Texas.

[6] Force XXI is the transformed Army of the 21st Century—in its entirety. The central and essential feature of this Army will be its ability to exploit information (Army Director, Louisiana Maneuvers Task Force, 1995).

the information to avoid misleading or misinforming. The speed with which information processing and communications technologies can manipulate and transmit data means that erroneous information, misinterpreted information, or misunderstood information that is improperly processed and repeated electronically throughout the battlefield can make a bad situation worse and can do so very rapidly.

SUMMARY

The Army has recognized the power of information and the technologies for handling and processing information on the battlefield. A smaller Army, based primarily in the United States and required to respond rapidly to worldwide contingencies, must have continuous access to accurate, current information. Commanders must be able to use information and protect it. Commanders at all echelons must have a shared, common understanding of real-time battlefield truth. Misinformation can be potentially disastrous. Without accurate, timely information and the communications to ensure its availability to commanders and staffs throughout the battlefield, a smaller U.S. force may not prevail against a determined enemy with reasonably modern technology.

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3— Review of Relevant Commercial Technologies

In this chapter, the committee describes trends in commercial multimedia building block technologies. The technologies that are described were selected by the committee in the context of a layered architecture that is relevant to generic multimedia applications. In addition, there is discussion of some commercial, system-level applications of multimedia information technologies and some important lessons learned in the application of multimedia technologies in commercial venues. This chapter serves as a technical foundation for recommendations made later in this report.

MULTIMEDIA ARCHITECTURE

The committee configured a generic layered architecture as a basis for identifying building block technologies that are relevant to Army multimedia communications. This multimedia architecture is depicted in Figure 3-1.

The purpose of the committee's generic architecture is primarily for discussions of how a set of relevant building block technologies relate to each other. It does not represent a fully fleshed-out technical architecture.[1] The importance of a technical architecture is discussed in Chapters 4 and 6 and in the related recommendations in Chapter 7 of this report.

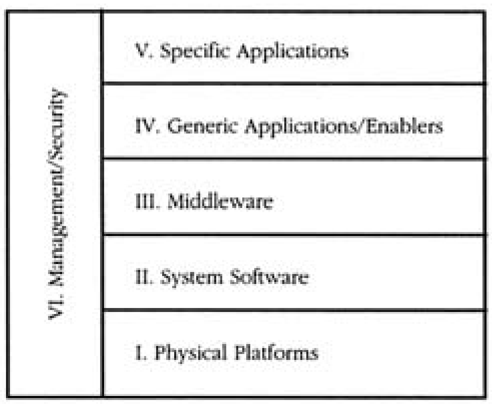

Figure 3-1
Generic architecture for multimedia communications.

The committee's architecture consists of several generic layers. The naming of the various layers of the architecture explicitly reflects the fact that multimedia technologies are strongly dependent upon software. With the generic architecture as a framework, the committee selected relevant multimedia technologies and overlaid them onto the various layers of the architecture (see Figure 3-2). Generally, but not always, higher layer technologies employ the services of lower layer technologies. Note that the building block technologies are numbered in Figure 3-2 from bottom layers to top layers in order to facilitate later discussions.

The bottom layer of Figure 3-2 (Layer 1) includes physical devices, subsystems, and systems (e.g., lightweight portable terminals, storage systems, and communications subsystems and systems to support people on the move). The next level (Layer II) provides protocols for interconnecting subsystems, systems, networks and gateways, operating systems for managing computational resources, and distributed computing environments for managing distributed software processes. The middleware (Layer III) is built on top of the lower level system software and provides capabilities such as information filtering, database management, and user-friendly multimedia user interfaces. Layer IV provides generic applications/enablers such as multimedia teleconferencing capabilities and groupware,

[1] A fully fleshed-out technical architecture would not merely say that certain building block technologies lie in certain levels of the architecture. It would specify, for illustration, the Internet protocol or one or more alternative protocols as the protocols to be used for specific applications; it would specify a graphical user interface (e.g., Motif or one or more alternatives) as the graphical user interface to be used. Where more than one alternative is specified as acceptable for a specific building block, the documentation supporting the technical architecture would explain why there is more than one acceptable alternative, provide guidance regarding which alternatives should be used in which types of applications, and explain how interoperability is to be achieved between applications using different building block alternatives.

which can be tailored for specific applications (e.g., simulation) at the top layer (Layer V). Woven through the architecture are network management and security technologies to provide reliable, secure information processing (Layer VI).

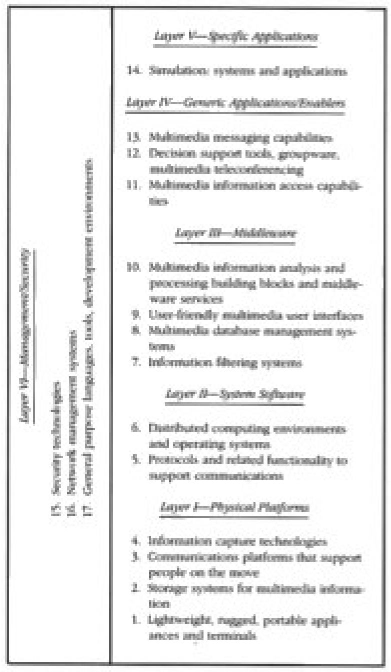

Figure 3-2
Building block technologies in the generic multimedia architecture.

The description of building block technologies in the sections below follows the arrangement of Figure 3-2. The value of doing this will become more apparent in Chapter 4, where it will be shown that these technologies and layered architecture concepts can be used to clarify the recommendations for how the Army should proceed to acquire the technologies to meet its operational needs and functional requirements.

The building block technologies described range from physical technologies, such as hand-held multimedia appliances and physical storage subsystems, to technologies that are embodied in algorithms and software (e.g., speech recognition and distributed computing technologies). They are discussed in the order of the six layers of the generic technical architecture (Figure 3-2).

In the discussions of these building block technologies, the focus is on the current status and likely trends in each technology, with particular emphasis on how large the respective commercially driven research and development (R&D) efforts are likely to be. These discussions have been kept brief to avoid unnecessary technical detail and include only what is needed to support the recommendations in Chapter 4.

BUILDING BLOCK TECHNOLOGIES

(Layer I—Physical Platforms)

Building block technologies discussed under Layer I—Physical Platforms of the generic architecture (Figure 3-2) include lightweight, rugged, portable appliances and terminals; storage systems for multimedia information; communications platforms that support people on the move; and information capture technologies.

Lightweight, Rugged, Portable Appliances and Terminals

During the first half of this decade, portable laptop and palmtop computers have grown into a multibillion dollar industry (based on sales of these computers in 1994). At the same time, these appliances have shrunk to the point where laptop computers provide the full functionality of bulkier desktop computers, except for the smaller display and keyboard, and weigh less than five pounds. Personal digital assistants (PDAs) for general purpose and special purpose applications are emerging in the marketplace. For example, they are being used by rental car agencies to expedite check-in and by delivery services to track the real-time status of packages in transit. In this section we examine the hardware component technologies—the processing chips, memories, storage devices, displays, and batteries—underlying these portable computing appliances and terminals to illustrate the rapid technological evolution of these appliances and terminals that is enabled by the underlying technology trends and driven by commercial market opportunities.

Processors

At the heart of every computing device is a central processing unit (CPU), a processing chip that "executes" the instructions the computer is programmed to perform. While CPU capabilities can be characterized by various metrics, the MIPS (millions of instructions per second) that a processor can execute is one commonly accepted measure of performance. In 1994, microprocessor CPUs were announced with a rating of 1,200 MIPS—an impressive figure given that CPUs found in many personal computers produced in the late 1980s and early 1990s were rated in tens of MIPS. Such remarkable, order-of-magnitude increases in processor speeds have been commonplace over the past decade, and there is every indication that processor capabilities will continue to increase in the foreseeable future.

Memory

The increasingly sophisticated operating systems and application programs used in today's computers are often characterized as being "memory hungry." They require more dynamic random access memory (DRAM) than their earlier counterparts in order to operate efficiently. One indication of this trend is the fact that the average amount of DRAM memory used in a personal computer has grown from 0.5 megabytes in 1984 to 8 megabytes in 1994, a 16-fold increase (Geppert, 1995). Fortunately, this increase in memory needs has been matched by a 20-fold decrease in memory costs over the 1982–1992 period.

Trends in increasing memory density (i.e., the number of bits on a single chip) are expected to continue for the foreseeable future, with a factor-of-four increase every few years. Sixteen-megabit DRAM chips are now common, and memory chip producers are assembling manufacturing facilities for 64-megabit chips. Hitachi and NEC announced early designs for a 1-gigabit memory chip at a conference in February 1995. While such gigabit DRAMs are not expected to be produced in volume until the first years of the next century, a continued dramatic trend in increasing memory densities is evident.

Permanent Storage: Disk Drives and Flashcards

The miniaturization trends for CPUs and memory noted above are also evident in the area of disk drives, the traditional storage media for data that must be stored for extended periods of time. Disk drives for laptops are now available in so-called PCMCIA cards (Personal Computer Memory Card International Association), which are lightweight, credit-card-sized devices that can be easily plugged into a laptop computer.

Disk drives have mechanical parts and thus require sophisticated technology (such as liquid-bearing motors) for use in laptops, where ruggedness is a concern. A recent competitor to disk drive technology, and one that is based on semiconductor technology containing no movable parts, is the so-called PCMCIA "flashcard." Currently, flashcards have less storage capacity than disk drives and are significantly more expensive, costing about 15 times more than comparable disk drives. However, as flashcard technology is relatively new, prices may fall as the technology matures. Current flashcards can store 16 megabytes of data; 256-megabyte flashcards are expected to be available in 1997 (Geppert, 1995).

Display Technology

The need for lightweight and rugged displays for portable computers and the quest for flat screen television sets are the driving forces behind display technology. Laptop display technology can broadly be classified into passive liquid crystal display (LCD) technology and active LCD technology. Active matrix LCD (AMLCD) technology is the more recent of the two and was developed to overcome some of the difficulties associated with passive displays. Companies have spent an estimated $3 billion to commercialize AMLCDs. The cost of a manufacturing facility for AMLCDs is very substantial; it is estimated that a single state-of-the-art AMLCD production line exceeds $100 million (Werner, 1993).

In addition to ongoing commercial AMLCD research, there is continuing commercial research on developing portable displays by improving upon passive LCD technology. Another commercial initiative of interest is a push to develop lightweight and durable displays based on plastic LCDs.

The emergence of high definition television (HDTV) as a consumer technology will fuel consumer demand for low-cost high resolution displays, particularly in the larger sizes usually associated with television viewing. This demand should, in turn, further stimulate investments by commercial display manufacturers in all types of high resolution displays, including flat panel displays using the technologies described above. The large physical size of conventional cathode ray tube (CRT) HDTV receivers (particularly the depth) will make them impractical for many households. The commercial market opportunity available to any company that can create a large flat panel display technology suitable for residential entertainment applications is enormous, and this drives the large investments being made with respect to research on new manufacturing methods and entirely new approaches to creating displays.

The underlying display technologies described above are being incorporated into novel commercial products such as virtual reality glasses or goggles and automotive "heads-up" displays. Virtual reality glasses or goggles use small liquid crystal elements and combinations of lenses and mirrors to create a virtual image that appears to the wearer to be projected in front of the wearer as a large image at a distance of several feet. In some cases, these virtual reality glasses or goggles are used to immerse the viewer in a visual environment that fills the viewer's sensory visual field of view and thus creates the sensation that the viewer is part of the three-dimensional environment perceived. Heads-up displays use projected images to superimpose information on a window or screen through which the viewer can observe other important information (e.g., instrumentation information superimposed on an automobile windshield). These emerging technologies tend to be at the high end of normal mass market consumer price points (e.g., more than several hundred dollars) but are expected to experience rapidly declining prices as mass production and competition take hold.

Power and Batteries

Power consumption and better battery technology are also key technology factors in lightweight, portable computing devices. Many microprocessors and application-specific integrated circuits and memory chips are now being manufactured with decreased power requirements. Many now run at almost half the power requirement of previous chips, and many processors have a sleep mode in which only a minimum amount of power is consumed.

Batteries are used in a wide variety of applications ranging from small batteries in toys and hand-held consumer appliances to large storage batteries in automobiles and for backup power systems. Although not as dramatic as the progress that occurs each year in the performance of semiconductor-based components, there has been a steady improvement in battery technology and associated performance over the last several decades. Alkaline batteries have become very popular as primary sources for small appliances. A variety of new battery types, such as nickel-cadmium and lithium-ion batteries, have emerged as rechargeable power sources for appliances such as cellular telephones, cordless telephones, and notebook computers. Recent advances, such as plastic lithium-ion batteries, show promise of increased energy densities, improved safety and environmental friendliness, ruggedness, and low cost. Research continues on fuel cells and alternative large energy-storage batteries for automobiles and industrial applications.

The worldwide market for batteries is $26 billion per year, of which almost 40 percent is for consumer single use batteries. Because of the economic impact of battery technology on automobiles, telecommunications, consumer electronics, and ultimately trade, the major industrialized countries have been funding battery research via national consortia. As an example, the United States Advanced Battery Consortium, which includes General Motors, Ford, Chrysler, and the U.S. Department of Energy, is a $260 million (total over several years) joint government-industry effort to develop advanced batteries for electric vehicles (Shokoohi, 1995).

Personal Digital Assistants

Personal digital assistants (PDAs) are extremely light-weight and compact hand-held computers. Rather than relying on a keyboard, PDAs use a stylus together with a touch-sensitive screen for input. Long-term data storage is provided via PCMCIA cards. PDAs can be used to maintain a small database (e.g., an address book), write and store notes, and send or receive electronic mail and facsimiles when plugged into a phone jack (or connected via a wireless modem).

PDAs were introduced to the marketplace in 1993. Difficulties with the handwriting recognition system in the first PDA may have limited its widespread acceptance. Other PDAs were introduced into the market in 1994 by many of the major international commercial consumer electronics, computer, and communications companies.

PDA technology is still relatively immature. No standard chip sets or common architectures have yet been adopted in the computer industry. From a user's point of view, PDAs also have a way to go. It has been predicted that it will take 10 years for PDA technology to meet its expectations (Halfhill, 1993).

Epilogue: The Personal Computer Industry

The component hardware in portable laptop and palmtop computers is closely tied with developments in the larger personal computer industry. In order to indicate the momentum and scale of the resources being invested in this area, the section concludes with some brief figures indicating the current and projected size of the personal computer market.

It is estimated that 16 million personal computers will be sold in the United States in 1995, with 34 million more machines being sold worldwide. The estimated installed base of personal computers in the United States is 80 million (approximately one personal computer for every three people) as of 1994, with 200 million worldwide. It has been estimated that the annual sales of personal computers will surpass 100 million units worldwide by the end of this decade (see Juliessen, 1995).

Storage Systems for Multimedia Information

Storage systems are used to store information that is needed for performing computational tasks, the results of which may be displayed or presented to end users or re-stored for subsequent use. As discussed above, storage systems are used in lightweight, portable appliances and terminals. They are also used as the physical platform for storing information in distributed, networked applications and for archiving information.

Storage systems range from archival storage systems such as magnetic tapes and associated tape drives (whose information may take relatively long to access) to magnetic disks and optical disks (whose information may take milliseconds to access) to semiconductor memory (whose information may take tens of nanoseconds to access).

Multimedia applications stress storage systems because multimedia objects such as images, voice clips, audio clips, and video clips contain many more bytes of information than text. For example, the storage requirements of various information objects can be compared as shown in Table 3-1 and described below:

A typical electronic mail message might contain 256 words. If we assume an average of eight letters per word, including spaces, and 1 byte (eight bits) required to represent each letter, then we require 256 × 8 = 2,048 bytes to store one E-mail message. A high resolution image might require 1,000 resolvable picture elements per line and 1,000 lines. This results in 1,000 × 1,000 = 1 million picture elements (pixels), each of which may require 3 bytes of data to represent all of the color and intensity information. The result is a requirement to store 3 million bytes of information to represent 1 high resolution picture. However, a lower resolution picture requiring only 256 pixels per line and 256 lines would result in a reduction of a factor of 16 in the storage requirements. Furthermore, by using image compression techniques to reduce redundant information, an additional factor of 20 in storage requirements might be possible. Thus images requiring 1 byte/pixel may be represented with acceptable quality with only 3,277 bytes of storage (for example). Speech can be represented with reasonably good quality at data rates of 8–16 kilobits per second. A speech clip lasting 60 seconds and represented at 16 kilobits per second (kbps) would require 60 × 16,000 bits or 120,000 bytes of storage. Video is the most bandwidth and storage-intensive media type of commercial interest. Conference quality video can be supported by 64–384 kbps using current video digital encoding technologies, with 64 kbps representing marginal quality for desktop teleconferencing applications and 384 kbps being suitable for large screen teleconferencing or high quality desktop teleconferencing. Data rates of between 1.5 megabits per second (Mbps) and 6 Mbps are suitable for entertainment quality television comparable to today's standards for home entertainment systems, while data rates of 18–40 Mbps are needed for HDTV. Some examples of storage requirements for 60 second video clips are given in Table 3-1.

TABLE 3-1 Comparison of Storage Requirements

Media	Bytes
Text (256 words)	2,048
Image (1,000 × 1,000 pixels, 3 bytes per pixel, uncompressed)	3,000,000
Image (256 × 256 pixels, 1 byte per pixel, 20:1 compression)	3,277
Speech (60 seconds at 16 kbps)	120,000
Video (60 seconds at 384 kbps)	2,880,000
Video (60 seconds at 1.5 Mbps)	11,250,000

NOTE: Pixel=picture element; kbps=kilobits per second; Mbps=megabits per second.

There is intense competition in the computer industry to create improved storage systems, which (a) increase the amount of storage per unit area or per unit volume; (b) reduce power requirements; (c) reduce the time required to access stored information in terms of both the time it takes to begin accessing information and the rate at which information can be delivered from the storage system; and (d) have increased ruggedness.

With the increasing activity in commercial telecommunications focused on what is called "video-on-demand" (i.e., the ability to remotely access stored video information with individualized interactive control), there has been a surge of commercial efforts to develop the multimedia servers (storage systems) needed to store hundreds of full-length videos that can be simultaneously and independently accessed by thousands of users. A variety of architectures ranging from arrays of small disks and inexpensive multimedia-capable computers operating in parallel to supercomputer-like approaches are being tested in commercial technology and market trials.

Commercial and industrial server and storage systems for medical image archiving, electronic home shopping, educational applications, interactive games, and other applications that involve multimedia information are being driven by a perceived market measured in billions of dollars per year in server and storage system sales. These developments include the compact, rugged multimedia storage systems needed by notebook computers (discussed above), personal compact disk players, set top boxes (as described under Residential Information Systems later in this chapter), and other consumer appliances.

Communications Platforms that Support People on the Move

"Wireless personal communications" is a commercial telecommunications industry term for networking services and associated applications that support people on the move (IEEE, 1995). Cordless telephones, cellular telephony, and paging systems are the most popular current manifestations of wireless personal communication systems.

Cordless telephony started as a low-cost, low-power, short-range (a few hundred feet) home appliance intended to eliminate the tether to the telephone network. The concept has blossomed into cordless telephones that people can carry away from home and operate anywhere within reach of a compatible base station. The CT2 Common Air Interface is a standard used in the United Kingdom, Canada, and Hong Kong and other parts of Southeast Asia. These systems have been optimized for cost, and the handsets are extremely light and portable.

The Digital European Cordless Telecommunications system provides an advanced design that supports higher user densities. It uses small "picocells" and resembles a cellular system as much as it does a cordless system. It supports data transmission as well as voice.

The Personal Handyphone System is specific to Japan. The system is designed to provide a single, small, portable phone that can be used at home or office (already launched) or as a public access device (to be launched this year). The system will support fax as well as voice. The potential subscriber base is estimated at 5.5 million in 1998 with up to 39 million by 2010 (Padgett et al., 1995).

In the United States, Bell Communications Research has developed an air interface for a Wireless Access Communications System (WACS). By combining parts of the Personal Handyphone System with WACS, the proposal is now called Personal Access Communications Services. The goal is to provide wireless access to the wireline networks of local exchange carriers. Base stations are expected to be shoe-box-sized enclosures mounted on telephone poles about 600 meters apart.

In contrast to cordless systems that were developed for people walking around, cellular systems were originally intended for vehicle applications. The first generation systems, called Advanced Mobile Phone Service (AMPS), use analog modulation for speech and base stations with coverage of 10 km or less—in some cases as little as 0.5 km. These systems have been widely deployed (see discussion of cellular elsewhere in this report).

As the cost of digital electronics has continued to drop and low-rate digital speech coding techniques have continued to improve, digital versions of cellular have begun to appear. The European Global System for Mobile Communications (GSM) is expected to improve quality over systems like AMPS and to provide pan-European roaming. The GSM standard also includes specifications for synchronous and asynchronous data services at 9.6, 4.8, and 2.4 kbps.

In the United States, the Electronic Industries Association and the Telecommunications Industry Association adopted a standard called IS-54, where IS stands for Interim Standard. IS-54 equipment is operational in most of the top U.S. cellular markets, and customer adoption is increasing. A second Interim Standard, IS-95, is based on a different frequency sharing scheme called code division multiple access (CDMA), which was originally developed to increase jamming resistance for military applications. This is a relatively new approach, with the first systems expected to be deployed in California this year.

Manufacturers of cellular hand-held units must address two fundamental markets. The first, sometimes called the "road warrior," is a user whose livelihood actually depends on phone contacts made while on the move. Sales people are an obvious example. These users demand high quality voice transmission and reliable connections. They are also the leading buyers of premium services and features, and they are relatively insensitive to prices. The second major group is the "casual user." They are more concerned about price and are more tolerant of lower voice quality or occasional dropped connections. Manufacturers sell far more casual-user phones than road-warrior phones, but the latter are very important to carriers because they generate many more minutes of usage. The net result is that manufacturers are driven to produce both a simple, high-volume, low-cost product line and a lower-volume, higher-cost, feature-rich line of handsets.

In contrast to voice, there are fewer systems and standards (so far) for wireless data services. Wireless local area networks (LANs) are usually privately owned and operated and cover very small areas. These are generally intended for high data rates (greater than 1 Mbps) and operate in unlicensed spectrum. Standards for wireless LANs are being developed under the Institute for Electrical and Electronics Engineers (IEEE) 802.11 committee in the United States and under the European Technical Standards Institute RES10 committee in Europe (HIPERLAN). Wireless LANs can be used to form ad hoc and quasi-static networks, although full roaming mobility is not yet available. Generally, the subscriber units require a hub with which to communicate although there are exceptions. Some operate at data rates of several megabits per second, approaching that of a wired Ethernet. Many are sized to fit on a PCMCIA card.

The Advanced Radio Data Information Service (ARDIS) in the United States covers much wider areas using specialized mobile radio (SMR) frequencies in the 800 to 900 MHz range. There are over 50,000 subscribers today, and service is offered in over 400 metropolitan areas. The prevailing data rate is 4.8 kbps, with 19.2 kbps available in some areas. Cellular digital packet data is another approach that reuses existing analog cellular networks. It is a transparent overlay to AMPS systems, taking advantage of idle time on analog channels. The European GSM infrastructure, already digital, is developing the General Packet Radio Service to handle data.

Satellite communications systems allow for a rapid expansion of communications infrastructure and provide connectivity to isolated locations. Commercial satellite services are designed to provide coverage to predetermined geographic areas, and their ability to redirect or expand this capacity is very limited.

More Ku-band (14/12 GHz) systems are being deployed to augment those at C-band (6/4 GHz). Also, Ka-band (30/20 GHz) has been set aside for commercial satellite communications, and equipment for this band is in the experimental stage in the United States. Utilization of Ka-band began in Japan and Italy in 1990. These trends imply that significantly more capacity will be available in orbit (IEEE, 1990; Manders and Wu, 1991).

Very Small Aperture Terminal systems are being used to provide two-way data services (T1 rates, 1.544 Mbps) to small terminals. Direct Broadcast Services (DBS) now transmit data at rates of tens of megabits/second to small terminals (less than about 2 feet in size). However, both of these latter services are available only in selected coverage areas.

There are several commercial satellite systems for personal communications currently in planning and development phases; examples are IRIDIUM, Odyssey, Globalstar, and Inmarsat-P. These systems are intended to support users anywhere in the world. The Teledesic system of low-orbiting satellites would provide a very large number of medium-to-high data rate links (several megabits/second) to small terminals. These emerging satellite systems will represent more than $10 billion in development and construction (including lauch) costs when deployed (CDMA, 1994).

In addition to providing wireless links to end users, communications platforms that support people on the move must include backbone and feeder transmission and switching facilities that interconnect the wireless access nodes. Terrestrial nodes (e.g., cell sites) are typically connected with cable-based fiber optic or copper cable facilities and occassionally with point-to-point microwave facilities. The cable-based facilities that have been used to date have relatively low bit-error rates. The point-to-point microwave facilities used in commercial applications generally have relatively low bit-error rates as well (10-6 or lower) (Ivanek, 1989). Recently, there has been a great deal of commercial interest in the use of upgraded cable television systems to interconnect small cell sites in emerging personal communications networks. Since the cable systems carry combinations of frequency-division-multiplexed analog television, digitized television, and other digital information streams, and because of the characteristics of the existing cable facilities, the digital error rates on these systems are expected to be somewhat higher than in other commercial facilities. As a result, certain protocols like the asynchronous transfer mode (ATM) protocol that was designed for low bit-error rate transmission facilities will not work properly unless steps are taken to encapsulate these protocols inside an error-tolerant transmission format.

Steps are being taken by a number of standards bodies to create a transmission format that will allow ATM to be carried over facilities with relatively high error rates, like cable television facilities. This is considered a high priority issue because of the investments that existing cable system operators have in their current facilities and because of the announced plans of some local exchange carriers to deploy new multipurpose broadband networks based on combinations of fiber optic and coaxial cable. The ATM protocol is discussed at length later in this chapter under Protocols and Related Functionality to Support Communications.

Information Capture Technologies

Information capture technologies interface to the physical world to capture (sense) sounds, images, moving scenes, etc., electronically and to convert the captured information to digital forms that can be used by automated information systems.

In the past ten years, information capture technologies have become consumer products in the form of sophisticated, but moderately low-priced and highly usable, camcorders. These commercial devices can operate in a wide range of light levels under control of their internal micro-processor based systems and can provide features such as zooming and integrated sound capture (microphones and associated electronics). These devices can also communicate to videocassette recorders via interfaces provided for that purpose, and it is anticipated that next-generation camcorders will appear shortly with their video and audio outputs encoded in standard digital formats (e.g., the Motion Picture Experts Group (MPEG) MPEG-2 standard). Camcorders are generally priced in the range of several hundred to a thousand dollars, although advances in mass production techniques and the desirability of reaching price points below $300 to address mass consumer markets will lead to lower prices in the future. The emergence of desktop multimedia teleconferencing, including video and image capture, have led to the appearance of low-cost charge-coupled device (CCD) video and still image cameras on the commercial market in the $50 price range.

Associated with the emergence of these consumer devices, and with the continued demand for sophisticated multimedia programming by movie and television audiences as well as users of multimedia computers (e.g., games), is the continuing evolution of video processing systems that can be used to perform such functions as editing video and still images and combining video with superimposed text and images. Some of these are transitioning into consumer products as increasingly powerful computer technologies allow these functions to be performed on general purpose personal computers with appropriate software.

Another example of a sensor that has found widespread commercial use is the infrared sensor technology used in such things as motion detectors. These devices are available commercially in products costing only a few dollars and are used by consumers in applications including home security systems and automated driveway lighting.

Analog-to-digital conversion and other specialized sampling and data conversion tasks associated with sensors can now be performed easily with one or a few low-cost commercial chips, and associated signal processing can be accomplished with commercial single-chip digital signal processors. This development means that analog multimedia information such as audio, image, and video can be captured and converted to digital form easily and cheaply using commercial technologies. For example, IBM recently announced low-cost encoder ($700) and decoder ($30) chip sets that implement the MPEG-2 video compression coding standard.

BUILDING BLOCK TECHNOLOGIES

(Layer II—System Software)

Building block technologies discussed under Layer II—System Software of the generic architecture (Figure 3-2) include (a) protocols and related functionality to support communications, and (b) distributed computing environments and operating systems.

Protocols and Related Functionality to Support Communications

Network protocols are the system-level standards for formatting information, controlling information flows, reserving communications paths, authorizing access to communications resources, managing congestion, recovering from communication or equipment failures, determining routing, and other processing tasks needed to transfer or access data between remote end systems (e.g., users) in a network. Since even a brief overview of network protocols could fill an entire report, we focus here on two leading protocol architectures: the Internet protocol suite and the emerging ATM high-speed network standards. For each, we begin with a brief history and architectural overview and then consider the types of network services they support, with an emphasis on multimedia communication. Also, a "technology forecast" is provided for each. This section concludes with a discussion about software support for mobility.

The Internet Protocol Suite

The Internet protocol suite is the result of 25 years of evolutionary development, much of which has been sponsored by the Advanced Research Projects Agency (ARPA). In the Internet architecture, there is a clear distinction between the services to be provided by the network-level infrastructure and the services to be built on top of these network services by the communicating end systems. The division of functionality between the network and the end systems has proven to be a remarkably robust and prescient one.

At the heart of the Internet architecture is a design philosophy in which the network-level infrastructure provides only a simple, minimal packet delivery service. The Internet Protocol (IP) and the associated route selection protocols that provide this network-level service make no guarantees that (a) the packets sent by one end system will be received by the other end system, or (b) the network will deliver transmitted packets to the destination in the order in which they were sent. IP does not recognize any notion of a "connection" between two endpoints.

Any additional functionality (e.g., reliable data transfer) required by an end application is provided by "end-to-end" protocols which execute on the end systems. For example, the Transmission Control Protocol

(TCP) is an end-to-end service which uses IP to provide in-order, reliable delivery of data between two end systems.

From a service standpoint, the Internet protocol suite provides for both reliable (via TCP) and unreliable (via the user datagram protocol (UDP)) data transfer between two end systems. Multicasting of data (i.e., the copying and delivery of a single data packet to multiple receivers) is also supported. All Internet applications (e.g., file transfer protocol, remote login (telnet), E-mail, World Wide Web (WWW)) are built upon either TCP or UDP data transfer.

The Internet protocols provide no explicit support for real-time communication (e.g., interactive audio or video) or for applications that send information at a constant bit rate, and they require the stream of bits to be delivered with a very low delay variability among the bits in the stream. It should be noted, however, that several efforts are under way in the Internet Engineering Task Force (IETF), the Internet standards body, on developing protocols for supporting such services. Notable among these efforts is the RSVP resource reservation protocol (Zhang et al., 1993). It should also be noted that several efforts have demonstrated the possibility of multimedia teleconferencing over the current Internet (Casner and Deering, 1992; Macedonia, 1994). In principle, even the current Internet protocols can provide for teleconferencing services, as long as the network's traffic load remains low.

Since there is increasing interest in extending the use of the Internet to applications that require guaranteed packet delivery within a specified range of delays, such as real-time interactive multimedia teleconferencing, it is anticipated that the next-generation Internet protocol (IP version 6) will include mechanisms that enable network resources to be reserved and packets to be assigned priorities for transport through intermediate routers. Thus the Internet protocol suite is moving from its traditional connectionless "best effort" delivery approach toward a set of approaches that includes the equivalent of connection-oriented transport.

Internet protocols were initially developed for relatively low speed (e.g., 56 kbps) communication links. However, they have been shown to be able to handle traffic at rates of hundreds of megabits per second (Borman, 1989).

The current Internet protocols were developed for fixed-terminal (i.e., nonmobile) network users; this is reflected in the design of IP (and to a lesser extent, TCP and UDP). However, there has been considerable recent activity and interest in developing a new IP that will support mobility. Several efforts are currently under way in the IETF to develop Internet standards in support of mobility.

Nineteen ninety-four can well be characterized as the year that the Internet moved into the public consciousness. The reach of the Internet and the installed base is indeed impressive. There were 3,864,000 host computers in 154 countries connected to the Internet as of December 1994; almost 100 billion packets passed through a single National Science Foundation (NSF) net site in a single month (Bell, 1995). Industry and commerce are now relying on the Internet for services.

Security is also now a serious and legitimate concern for the Internet. Commercial needs and the increasing reliance on the Internet as part of our national infrastructure are fueling efforts in the area of network security both from the network standpoint (i.e., protecting the network from tampering) and from the end-user point of view (e.g., secure credit card transactions over the Internet and so-called "digital cash").

Asynchronous Transfer Mode (ATM) Networks

The development of ATM networks represents a meeting of the minds of the traditionally circuit-oriented (e.g., telephony) and packet-oriented (e.g., computer-related) communities. The push for ATM networks arose because of the recognized need to support high data transfer rates and a diverse set of applications (e.g., ranging from file transfer to real-time interactive multiparty videoconferencing) in a common integrated network.

Within an ATM network, data are carried in fixed-length packets known as cells. The cell format and associated network switching methods have been designed to facilitate very high speed operation (e.g., at 155 Mbps and above). The ATM architecture has been designed specifically to support a multitude of applications, ranging from bursty data to constant-bit-rate, real-time video. Consequently, ATM networks provide four service communication classes: (1) constant-bit-rate, real-time service (audio and video, roughly equivalent to today's telephone service); (2) variable-bit-rate, real-time service (audio or video, roughly equivalent to today's telephone service); (3) connection-oriented data (roughly equivalent to TCP in the Internet); and (4) connectionless data (roughly equivalent to UDP in the Internet). These four services can be offered over a single common network.

ATM has been designed to operate over transmission facilities which have relatively low bit-error rates (10^{-6} or less). Recently, consideration has been given to the transport of ATM over transmission facilities with relatively high bit-error rates, such as upgraded cable television facilities and certain types of wireless links. Standards activities have begun in the ATM Forum and the IEEE 802 Standards Committee to produce a standard method for encapsulating ATM cells along with error-correcting mechanisms for transport over facilities with relatively high bit-error rates.

Before 1994, ATM products and prototypes were being supplied by only a handful of vendors and installed primarily in research institutions and government labs. In 1994, however, more than two dozen vendors brought ATM switching products to market. Membership in the ATM Forum (the standards body most aggressively pushing ATM forward) has grown considerably. Nonetheless, ATM is a new technology that has not yet been demonstrated on nearly the same scale as the Internet protocols (ATM Forum, 1995).

Two visions exist regarding the use of Internet technology and ATM networks in the emerging national information infrastructure. In one view, interconnected ATM networks will provide seamless, uniform, end-to-end transport of ATM cells between any two endpoints. In the other view, ATM wide area networks will be used to connect islands of local area or campus networks, with the individual islands running Internet (or other) communication protocols. Both views are likely to be correct, in that applications exist in which the solutions implied within both views are viable. The balance between the use of one approach over the other will be determined in the emerging commercial marketplace, more by the speed at which commercial products emerge that meet user needs than by any fundamental advantage of one approach over the other.

Software Support for Mobility

One can consider three phases in the evolution toward the support of mobility in commercial telecommunications networks. The first, associated with traditional "plain old telephone service (POTS)," supports essentially no mobility at all. In this case the terminal equipment has a fixed relationship to the network to which it is attached, and the user has a fixed relationship to the terminal (i.e., one attempts to call a specific person by dialing a number associated with a specific physical location). There is limited support for mobility via extension telephones and cordless telephones, but these do not require any network-based intelligence. The second, the familiar case of today's cellular services, allows one of the relationships to be dynamic—namely, the physical location of the telephones is dynamic. However, the relationship between user and terminal equipment remains fixed (i.e., a particular cellular telephone and associated telephone number are still used to attempt to reach a specific user). In the third phase, the relationship between the user and the terminal is also allowed to vary, and it is the user, rather than a specific terminal, to whom calls are directed. This is called "personal mobility." The latter two phases require that software-controlled functionality be added to both the terminal equipment and the network.

Smart-card technology offers still further flexibility to personal mobility. Smart cards contain user-specific data that turn a terminal into a de facto peripheral for the card. With the smart card, the terminal takes on the personality and behavior that the user wishes (and has paid for), including feature sets, custom dialing control, and authentication passwords.

For systems in phase two, represented by today's cellular telephony, the approach to locating users (i.e., their moving terminals) who move from place to place is to maintain a system of home and visited databases called Home Location Registers (HLRs) and Visited Location Registers (VLRs). The HLR is the place to which an incoming call for a roaming user is initially directed based on the user's telephone number. The HLR will contain an entry that shows the VLR associated with the network in which the user is currently known to be located. This VLR knows that the user is in its domain because the user's telephone has communicated recently with one of its cellular nodes. The call will be forwarded to that network, where the VLR will arrange to have the call delivered to the proper roaming user, based on its stored information regarding the user's current location in its associated network. The VLRs will also notify the HLRs when roaming users move in and out of their domains.

To support full personal mobility, including smart cards, commercial network-based software will be upgraded and supplemented to include functionality not required in traditional fixed-terminal networks. In particular, fast inquiry and response database systems will be deployed to (a) interrogate terminal units and databases for user authentication, (b) interrogate databases for number translations, and (c) transfer service profile information from one information database to another as users and their terminals travel from place to place. Networks will be (re)programmed to recognize mobility-related numbers and respond to personal feature profiles associated with individual users.

Distributed Computing Environments and Operating Systems

Operating Systems Development

Operating systems are software systems that manage the hardware resources of a computer system to provide services needed by applications. They evolved from earlier input-output control systems, which were loaded into early computer systems before an application began to run; this was typically done with a deck of punch cards placed immediately ahead of the cards used for the application. It became clear that there was a common set of functions needed by many applications, and this gave rise to early operating systems. Early machines in many cases were dedicated to a single use. Later machines were multipurpose, but the input-output control system scheme made for sequential execution of jobs, one after another.

A major advance came from the idea of multiprogramming, which took advantage of the fact that the expensive processor was often wasted as slow input and output devices (such as printers, card punches, and tape machines) were accessed by an application. Multiprogramming used the idle periods of the processor to perform other computational work until the input and output were completed. A variety of multiprogramming techniques were developed, with fixed and variable numbers of tasks, priorities, etc. Timesharing is a multiprogramming technique that allows interactive access to the multiprogrammed resources.

Multiprogramming also involves sharing of processor memory resources. Modern multiprogramming technologies have almost uniformly employed the technique called "demand-paging." Demand-paging divides the storage of the machine into fixed-size units called pages. Application storage is also divided up into page-sized address ranges, which are mapped to the machine's storage through a technique known as virtual memory.

All commercial operating systems for workstation or larger computers (e.g., MVS®, UNIX® and its derivatives) now incorporate these techniques. Smaller systems, such as personal computers, have been evolving in the same fashion; the popular Windows application support software is essentially a single-user multiprogramming system overlaid on an extremely simplistic device-management core (MS-DOS®). Newer generations of personal computer software will support more advanced memory management techniques, such as demand-paged virtual memory. The lack of modern memory management technology in the popular MS-DOS® software has been a major limitation in using these commodity machines for more complex applications and a major source of failures. These difficulties have provided opportunities for alternative personal computer operating systems (e.g., OS/2®), as well as penetration of the personal computer market by UNIX® technology.

A major challenge remaining for operating systems is the efficient processing of multimedia data (Nahrstedt and Steinmetz, 1995). Multiprogramming systems have embedded assumptions about scheduling jobs that they inherited from their predecessor technologies. For example, they often schedule job execution in a "round-robin" fashion to preserve a fair allocation of processing resources between jobs. This scheduling creates a "virtual time" model where each job's real processing time (wall-clock time) is dilated in proportion to the amount of competition for processing resources.

Unfortunately, continuous media such as voice and video are characterized by their real-time requirements; 30 frames per second of video are required to preserve perceptual smoothness in spite of competing demands for resources. These real-time constraints suggest that the requirements of multiprogramming must be balanced against the application requirements for effective multimedia support in operating systems (Nahrstedt and Steinmetz, 1995). Substantial commercial R&D effects are underway to improve the support for multimedia applications in commercial operating systems. Examples include the XMedia® toolkit from DEC and the Hewlett Packard® MPower® toolset.

Interoperability and Distributed Computing Environments

In the 1970s and before, computer programs were usually written for only one hardware and software platform at a time. "Porting" a large application to another platform was a difficult task, rarely undertaken. The UNIX® operating system, which blossomed in the 1970s, owes much of its popularity to the fact that it was explicitly designed to run on multiple platforms and was closely wedded to the C programming language, which was also designed for portability. In the 1980s, portability was among the most desirable of attributes sought for computer applications.

In the 1990s, portability remains an important issue, but interoperability (the ability of computer applications developed by different vendors to cooperate on the same or different computing endeavors, and to share data between such applications) across software and hardware platforms has become the more sought-after attribute. Interoperability and the improving price-performance trend of small computer systems have led to intense interest in what is known as a distributed computing environment—a set of standard interfaces, software components, and tools that permit computer applications developed by different vendors to cooperate on the same or different computing environments interconnected by appropriate communication links.

In the past, incompatible software applications have proliferated. This has occurred because of (a) mixing programs written in different languages, and (b) the use of different ways to communicate between programs running on the same or different computers that are connected by a communications system. Cooperation across incompatible platforms was so difficult to achieve that applications were commonly designed with no intention of ever cooperating with other applications, thus further exacerbating the problem. Today, there are two major commercial approaches to distributed computing: client-server architectures and the Distributed Computing Environment (DCE) from the Open Software Foundation (OSF).

In a client-server architecture, client applications communicate with a server application in a structured manner in order to obtain a service from that server. In the Internet for example, a WWW client might request that a multimedia document be sent to it by the server which stores, and controls access to, that document. Client-server solutions are also used in database applications. Client-server solutions are typically used to build database applications; processing is distributed across a network of multiple clients using personal computers or workstations and one or more server computers where the database is hosted. Microsoft® Visual Basic and Powersoft® PowerBuilder are examples of commercial products that use the client-server architecture. Both of these products are limited to use on personal computers and employ proprietary languages, but they can communicate with servers that recognize SQL, a standard database query language.

The Open Software Foundation Distributed Computing Environment consists of tools and software components that can be used to build distributed applications in any language and on multiple-vendor computer systems. The DCE can be used to implement client-server architectures that are not limited to database applications. Digital Equipment Corporation's Distributed Computing Environment is the best known example of a product.

Standards for distributed computing specified by corporate alliances and based on object-oriented technology are just now emerging. Examples are the Object Management Group (OMG) Common Object Request Broker Architecture (CORBA), the IBM System Object Model, and MS® Object Linking and Embedding (OLE). These standards offer the promise of a market of interchangeable software components (i.e., not just whole applications), residing almost anywhere, that can be mixed and matched as needed. Competition between these alliances and uncertainties concerning the business case for software components remain as obstacles to the fulfillment of the promise.

BUILDING BLOCK TECHNOLOGIES

(Layer III—Middleware)

Building block technologies discussed under Layer III—Middleware of the generic architecture (Figure 3-2) include information filtering systems; multimedia database management systems; user-friendly multimedia user interfaces (e.g., speech, graphical user interfaces (GUI)); and multimedia information analysis and processing building blocks and middleware services.

Information Filtering Systems

One of the challenges of the information age is to use computing technologies to overcome the problems of information overload. More and more information, including multimedia information containing graphics, photographs, and audio and video clips, is being stored in digital form and made accessible over digital telecommunications networks. The question arises, "How will people find what might be most useful to them and sort through it all to obtain potentially useful information that is directed at them by others?"

While many challenges remain, there has been progress in using computing technologies to manage information overload. In fact, the astounding rate of progress in the power of low and moderately priced computers has made it possible to do such things as index every word in a document and to therefore be able to perform such tasks as "Find and display every place in this document where the words 'video clip' or the words 'audio clip' appear. Likewise, directories have been created on the Internet WWW that allow one to ask such questions as "Tell me the location of every document that has the words 'battlefield digitization' or the words digitizing the battlefield'." Using word spotting and more general speech recognition technologies it is becoming increasingly possible (but still very difficult) to index voice clips. Using pattern recognition technologies, it is becoming possible (but still very difficult) to automatically index images, and photographs. However, because these technologies are still somewhat primitive, indexing of audio, images, and photographs must be primarily done manually today, using keywords and other text to describe their contents.

There are commercially available products and commercial products under development that can "read" incoming electronic mail, including facsimiles (by using scanners to convert printed text to digital form), in order to sort them by such characteristics as the name of the sender, the list of recipients, or keywords in the content. Likewise, electronic news feeds and incoming telephone calls can be sorted automatically according to a profile specified by an end user. As an example, an electronic mail filtering agent can be installed on a mail server that sorts mail into three priorities. Mail from certain specified individuals (determined by their originating E-mail address) is sorted into the highest priority bin. Mail directed to a large number of recipients is sorted into the lowest priority bin. Everything else gets medium priority, except mail that contains the word "urgent" anywhere in the subject header or the body of the message. Such "urgent" mail is inserted into the highest priority bin. This very simple sorting profile, specified by the user, is remarkably accurate in sorting messages according to their actual priority.

A relatively new concept in information overload management is the concept of a mobile agent. A mobile agent is an executable computer process or application that can be launched into a network by an end user to perform specified tasks for that end user as the agent travels through the network from server to server. For example, a mobile agent could be launched to search databases for automobiles having a set of specified characteristics that are available for purchase. This exciting technology has been embodied in some early products, such as the General Magic Telescript® product, but there are many issues that need to be resolved before such mobile agents are widely used. In addition to standards that define the interface and the interactions between mobile agents and the servers they attach themselves to, there are still open technical issues regarding (a) the potential impact of agents on network and server congestion, and (b) more generally, the security impacts of executing processes or application software received over a network.

Multimedia Database Management Systems

The role of a database management system is to provide reliable and efficient data storage and reliable and efficient access (e.g., query, retrieval, update) of the data store by a potentially large user population. As such, it must provide for (a) the integrity and reliability of the data; (b) concurrent use of the data (e.g., "locking" a piece of data being modified so that concurrent users do not access a partially updated/modified version of the data); and (c) easy application, user access, creation, or organization of the data.

Current database systems typically employ a so-called relational data model, in which data are viewed as being stored in columns and rows. A relational database management system (RDBMS) provided access and querying over these data in terms of this row and column structure. The RDBMS was well suited for business data processing where applications such as payroll and accounting fit naturally into the relational data model. For more sophisticated forms of data, particularly multimedia data, where the item being managed is more complex, the relational model begins to break down. An example of such a complex multimedia object might be a meeting or briefing consisting of synchronized audio segments, video segments, and textual display.

Object-oriented database management systems (OODBMS) are considered to be better suited for managing such complex objects. In an OODBMS, a user sees a higher level of abstraction than in an RDBMS; data are encapsulated within an object and can only be accessed via OODBMS procedures associated with that object. For example, a multimedia briefing object might be accessed via OODBMS playout procedures, which provide for retrieval of media from the underlying storage device and synchronized delivery of the meeting's component media streams. Another important aspect of an OODBMS is the notion of an object request broker, which provides coordinated access to objects that may be distributed among many computers in a networked environment. ODMG-93 is the object-oriented database standard advocated by the OMG, and CORBA (Common Object Request Broker Architecture) is the platform-independent object broker service supported by Object Management Group. Although OODBMS are relatively new, they are already being considered for deployment in large-scale environments. For example, NASA plans to incorporate object request brokers into its Earth Observing System Data and Information System.

Because multimedia OODBMS manipulate media streams (e.g., voice and video) that have stringent timing, playout, and synchronization requirements, the underlying operating system and object stores must themselves support these requirements. The earlier subsection on protocols and the related functionality to support communications discusses these continuous media requirements in more detail.

Digital libraries are an important emerging application that will make considerable use of distributed multimedia OODBMS (Fox et al., 1995). Envisioned digital library applications currently being considered are thus likely to push forward the development of distributed multimedia OODBMS. These applications include querying and information filtering of multimedia data (see prior subsection on information filtering systems) and hypertext/hypermedia browsing capabilities, which allow users and applications to navigate through the information in a nonlinear fashion (i.e., jumping from one piece of information to another piece of information in any desired sequence). Although commercial, networked, multimedia database technology is currently not available to support these applications, the significant efforts currently under way suggest that this component technology will mature as digital library efforts continue. For example, NSF, ARPA, and NASA have recently begun cooperating on a $24 million digital library research program. Both the U.S. Library of Congress and the British Library are undertaking significant efforts to provide multimedia access to their information (Purday, 1995; Becker, 1995). The Encyclopedia Britannica has recently begun providing an on-line multimedia access service to its encyclopedia through the WWW.

User-Friendly Multimedia User Interfaces

While early computer users were tolerant of arcane means of communication with the machine (i.e., punch cards, paper tape, teletypewriters, and character-based displays), today's users expect and require ease of use, implying ease of interaction. This has given rise to the mouse or trackball as a representative point-and-select device and bit-mapped displays (capable of displaying graphics and images) as a means of visual representation.

Since there are many situations where hands-free operation is desirable (e.g., operation of a car phone), speech recognition technology is becoming increasingly important and popular.

Origins of Speech Recognition Technology

Speech recognition research began at a number of industrial research labs and universities in the 1950s. Early systems could only be used for the recognition of isolated or discrete speech, consisting of a single or a very limited number of words spoken slowly and deliberately. High levels of accuracy also required a complicated tuning of the system for an individual speaker's characteristics. In the early 1960s, computers were capable of only millisecond instruction execution times and had very limited memory capacities. To perform any significant level of analysis in a pseudo-real-time nature on speech requires computer instruction execution times closer to the nanosecond range and substantial random access memory. Thus, based on the complexity of the analysis, the amount of computation involved to handle a fully continuous speech pattern from any random speaker, and the relatively limited amount of computing power available in the 1950s, 1960s, and even 1970s, practical speech recognition was far from a reality during this period.

New Directions

As computing capabilities increased it became much more practical for a useful voice recognition system to be built. Major research advances in the fundamental algorithms for speech recognition occurred during this time.

By the early 1980s it became possible for a small mainframe system about the size of a desk, supported by three special-purpose array processors in individual equipment racks and coordinated from a single workstation, to recognize a vocabulary of roughly 5,000 words. Such a system was used to generate office-style correspondence.

In the mid-1980s, it was possible for a personal computer, aided by a dozen special-purpose or "feature" cards housed in a separate chassis, to perform at the same level of speech recognition as the small mainframe had a few years earlier. As the power of personal systems continued to improve, a desktop personal computer with a single additional feature card housed within the system unit could perform office-style speech recognition with a vocabulary of 20,000 words.

Current Speech Recognition Systems

Personal-computer speech-recognition packages have been available on the commercial market for about five years. Initial offerings were of most interest to the very curious, highly skilled users with a significant discretionary budget. All required additional specialized hardware to operate. The most recent wave of product releases, however, has broken that barrier, running on standard platforms without expensive additional hardware. For the moment many retain some level of speaker-dependence, which requires some degree of training of the system for each speaker and limits the ability to handle truly natural, continuous speech. However, there are product offerings that are capable of handling continuous, speaker-independent input, with a vocabulary capacity of 25,000 words.

Programs permit dictation of text directly into a voice-aware application, working in conjunction with word processors and the like. They incorporate on-line error correction based on context and typically incorporate a learning feature that allows the system to improve its recognition of the user's speech with continued usage.

Another variety of speech-recognition software is the "voice navigator," which in conjunction with a simple sound card permits the user to interact with common operating system commands, menus, etc., through voice control rather than mouse and keyboard input. The navigator takes the spoken input commands to pull down menus, makes selections, and launches and closes applications. Products available also provide verbal input to many common applications or can be taught how to handle new ones. This has found application, for example, in voice-controlled dialing of cellular phones in automobiles, where the hands-free operation prevents distractions which may interfere with driving.

The last category of speech recognition systems available today is the development tool kits for C or Basic. These software packages permit the programmer to construct voice-enabled applications and add voice recognition to existing applications for specific tasks. Such applications might be of a forms type, requiring that specific fields of user information be filled in with verbal input.

Speech recognition has advanced far beyond the early experimental systems of the 1950s; however, it is not yet a mature and widely adopted application like spreadsheets or word processors. The next few years will probably see that change, as these mature applications in use on millions of personal computers in both industrial settings and personal environments are opened up to include voice annotation and support.

Graphical User Interfaces

Graphical user interfaces have found heavy use in industry as they have allowed people to interact effectively with computers without mastering a huge vocabulary of obscure syntax. Further, standardization of these interfaces to provide a common "look-and-feel" has proven to be a powerful technique for speeding user learning of the system. Much of this work has come out of the computer-human interface community, and a good deal of the fundamental work sprang from early systems explorations at the Xerox Palo Alto Research Center. For example, the Apple Lisa® and its commercially successful derivative, the Macintosh ®, had their origins in this work. The success of icon-based windowing environments, such as that of the Macintosh®, led to the realization that graphical user interfaces were a key enabler of widespread and effective use of computer-based applications. The creation by Microsoft of its MS®-Windows® operating system is indicative of this realization.

Industry has focused on selecting a standard environment in which to build applications. This has been accomplished by standardizing and using X-Windows® and Motif-based graphical user interface libraries.

Multimedia Information Analysis and Processing Building Blocks and Middleware Services

As the information technology industry has matured, there has been a trend toward moving what may begin as application-specific software out of applications and into a set of generically useful capabilities that application developers can draw upon and reuse. These capabilities can be combined into applications as reusable generic building blocks, or they can be accessed as remote resources provided by servers.

For example, if one wishes to convert text to speech or text to facsimile format, one could start from "scratch" and write application software to perform these tasks. However, since this ability is required by a large number of different applications, it makes sense to implement the functionality as generally usable building blocks, or *middleware* , rather than as application-specific software. Other examples of middleware include directory functionality, protocol interface functionality (e.g., functionality that allows stored data to be formatted and sent over the Internet protocol), security and access control functionality, video and image compression or decompression functionality (e.g., Motion Picture Expert's Group (MPEG) and Joint Photographic Expert's Group (JPEG)), user interface functionality, multimedia format conversion functionality, and various approaches to automatically sorting or indexing multimedia information (Wallace, 1991).

There are two important advantages to implementing generic information analysis and processing building blocks in the form of middleware. The most self-evident advantage is the efficiency that results from the reuse of generic building blocks. The other advantage is in interoperability. When generic building blocks are reused, there is much less likelihood of incompatibilities resulting from different design approaches or different implementations of what is intended to be equivalent functionality. The reuse of generic functionality, embodied in middleware, will likely be critical to achieving interoperability in large, distributed systems supporting a wide variety of applications.

BUILDING BLOCK TECHNOLOGIES

(Layer IV—Generic Applications/Enablers)

Building block technologies discussed under Layer IV—Generic Applications/Enablers of the generic architecture (Figure 3-2) include multimedia information access capabilities; decision support tools, groupware, multimedia teleconferencing; and multimedia messaging capabilities.

Multimedia Information Access Capabilities

One large class of applications of multimedia information networks is in making stored multimedia information accessible to others. Information access is a generic enabling application that can support a wide range of specific application domains ranging from electronic libraries to home shopping to medical applications involving stored patient records.

To make information accessible, it must be stored in a database server capable of storing the types of information desired (e.g., videos in the case of video-on-demand applications) and capable of managing the information to make it accessible to multiple users. Storage and database management technologies are building blocks that support information access. Likewise, information access requires directory and filtering capabilities to make information discoverable by users and their applications and to sort through information to find what is needed. Information access requires the existence of useful information in formats suitable for electronic storage and retrieval and thus the existence of information creation (authoring) tools. Information access requires (a) communications networks to allow information to be retrieved by users from remote servers; (b) security mechanisms to control access; (c) billing mechanisms to allow users to be changed for accessing the intellectual property of others; and (d) interworking capabilities that allow a diversity of terminal types (i.e., end user appliances) with a diversity of communications capabilities to access stored information with the maximum degree of facility permitted by the limitations associated with those terminals and communications capabilities. For example, users of the Internet WWW may or may not want to receive graphics and images, depending upon the speed of their access arrangement (e.g., dial-up modem vs. T1 line) and whether or not their terminal is configured as a bit-mapped display.

The aggregation of appropriate building block technologies, the establishment of standards for interfaces, formats, and other aspects of protocols, and the integration of these into generic information application building blocks for widespread use across a wide range of application domains are currently being pursued by the emerging information networking industry to meet existing and anticipated market demand. Although a full suite of industry standards has not yet emerged, the products that are currently appearing to support access to the Internet WWW and its commercial counterparts (e.g., America On-Line, Prodigy, the MS® Network, McInet), as well as the efforts under way to build multimedia client-server application software for interactive video-on-demand applications, illustrate the substantial level of commercial R&D resources being applied.

Decision Support Tools, Groupware, Multimedia Teleconferencing

Traditional decision support tools have included rule-based systems, simulations, and spreadsheet-like analyses. These have typically developed as single-machine and single-user tools, although they have, in some cases, incorporated sharing of data. They are widely used to support operations (e.g., the optimized routing of trucks and couriers, the ordering of materials and components, and for testing "what-if" questions that can be quantified in a form that a spreadsheet or other analytical tool can manipulate).

These tools have extended value if they can be used to support collaborative decision making. This potential has been recognized by industry, which uses "shared information" in corporate information systems. The financial industry allows for automated decision making for some investment decisions (e.g., so called "program trading," which monitors real-time stock market data looking for a trading opportunity).

Advances in networking technology coupled with increases in the visual and audio input and presentation capabilities of end-user terminals and appliances have enabled much greater collaborative capabilities. In particular, several commercial systems (such as BBNs Slate®, Lotus Notes®, and Intel's Proshare®) provide collaboration environments, and there are now tools emerging for supporting collaboration on the Internet. In particular, the "wb" program supports a "shared whiteboard" model of communications for sharing of graphical information, and the "vat" tool allows for audio teleconferencing over the Internet.

Widely available software tools for video teleconferencing include the CUSeeMe tool available from Cornell University, and commercial tools such as Sun Microsystem's ShowMe® tool, IBM's Person-to-Person ® multimedia conferencing software, and Silicon Graphics InPERSON® Desktop Conferencing Software. Internet technology, called the Multicast Backbone (Mbone), is now able to carry limited numbers of multicasts of video across the existing global Internet using slow frame rates, compression, and overlay support in Internet routers. This technology is maturing at an extremely rapid rate, as many entrepreneurs as well as large vendors see opportunities for sales of software, multimedia peripherals, and services. No standard has yet emerged for many of these environments, and it is reasonable to expect that it will take several years for the commercial world to converge on either one "de facto" standard (likely, because these collaboration tools must easily and reliably interoperate) or a very small number of such standards.

Multimedia Messaging Capabilities

Voice mail, fax, and text E-mail (electronic mail) messaging are popular generic applications that allow people to communicate on a non-real-time basis and to communicate images. The technology for multimedia messaging is similar to the technology used for current text-based electronic mail and has similar requirements for addressing, security, and management of messages. The difference is that the information in the message can have components representing a variety of data types (e.g., text, image, graphics, audio clip, video clip, data-structure) with each type possibly occurring in a variety of standard formats.

The simplest way to construct a multimedia message is to encode the multimedia information components, such as voice, in a set of formats that are recognized by the intended recipient. The encoded message file, while possibly voluminous, is then transported intact between source and destination. This end-to-end method is commonly used on the Internet today. Examples might include the end-to-end transmission of compact-disk-standard digitized audio, PostScript® images, and GIF and JPEG images. The recipient (or the recipient's mail reader) accepts and converts the encoded data back into the appropriate form for replay or display (e.g., audio, images).

The message can be augmented with indicators of the types of components and standard formats used for each component within the multimedia message. This is done, for example, with the Eudora® mailer, which provides a facility for multimedia "attachments" to textual message contents so that the text and the multimedia or program executable accompany each other through the mail transport subsystem.

By structuring the multimedia message this way with explicit indicators of its components and their formats, it is possible for intermediate systems to assist the recipient's end system in converting various components of the message into formats that are compatible with the end system's capabilities (e.g., E-mail text might be converted to synthesized voice or to fax format).

While multimedia messaging capabilities have not been completely standardized to date, it is expected that many features will be standardized as mailers and mail readers evolve to accommodate multimedia. A recent multimedia messaging standard, Multi-purpose Internet Mail Extensions (MIME) that has been adopted by the Internet Engineering Task Force (IETF), defines how components of a multimedia message and their formats can be explicitly identified within the message as described above. Multimedia mail is expected to be a widely used, popular generic application supporting a wide variety of commercial, residential, and institutional application domains.

BUILDING BLOCK TECHNOLOGIES

(Layer V—Specific Applications)

General Observations

Specific Applications, which form the top layer (Layer V of Figure 3-2) of the committee's generic architecture, draw upon and combine the functionality of lower layer building blocks and add additional software-based functionality to those building blocks to enable a set of useful tasks to be accomplished. Applications can be designed to be generically useful in a wide range of application domains; they are capable of being tailored (programmed) by users to meet their specific needs; or they can be designed from the outset to serve a narrow set of purposes for a specific application domain or even a specific individual user. For example:

- The MS® Word® application is a generically useful word processing application that can be used by almost anyone in almost any business, institution, school, or library. It makes use of a graphical user interface and a database management system as underlying building blocks, as well as the basic operating system and physical computing hardware upon which it runs.
- The Intuit® TurboTax® application is specifically targeted toward the preparation of income tax returns, but it can be used by a wide number of individuals having a wide variety of tax situations.
- A financial management, payroll, and accounting application might be designed or customized for an individual firm, or it might take on a more generic form specifically targeted, for example, to lawyers in private practices.

Whether or not an organization would develop a customized application or adopt a generic off-the-shelf application depends upon how unique its needs are perceived to be, and whether it wishes to use that application to obtain an advantage over its competitors. For example, a lawyer would not likely view an accounting application as a path toward obtaining a competitive advantage, but a major banking institution might view an accounting application as a principal source of competitive advantage.

It is useful to note that it is not unusual for applications to migrate from Layer V of the generic architecture into Layer IV to become generic/enabling applications. So, for example, as spreadsheets have become embedded as a building block in more complex or specialized applications, they have taken on Layer IV functionality, while at the same time general purpose spreadsheets such as MS® Excel® are also viewed as stand-alone applications in Layer V of the architecture.

There are many specific commercial multimedia applications, some of which were alluded to above and others of which are discussed later in this chapter. Since our discussions with Army personnel highlighted the important role of simulation in training, analysis of alternatives, and pre-engagement practice, the committee has specifically focused on simulation as an application to be discussed.

Simulation: Systems and Applications

This section reviews the basic categories of models and simulations needed to understand where commercial technologies are currently positioned and where they are headed. We begin with basic definitions (DoD Modeling and Simulation (MS) Management, 1994):

- A model is a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process. Typically, computerized implementations take the form of rule-based, stochastic, or deterministic models.
- Simulation is a class of techniques for testing, analysis, training, or entertainment in which real-world systems may be combined with computerized models.

Simulations have been categorized as:

- Constructive, which involve primarily computer calculations and representations combining selected aspects of the real world that have been previously analyzed and reduced to a mathematical model.
- Virtual, which are simulations in which people play a central role as themselves. Virtual reality is provided by computer- driven displays and interaction interfaces. Such simulations can be conducted as a single site or distributed across a network.
- Live, which attempt to make the action seem as real as possible to the participants by including live elements in the simulation.

Distributed Interactive Simulation (Bouwens et al., 1993) is defined as the execution of models at disparate sites, with humans-in-the-loop, linked for a common purpose and having a common view of that purpose. Information and data between sites (nodes) is passed using predefined protocols. The nodes can be distributed anywhere in the world, in any number, and they can operate with different hardware and software.

Constructive and virtual simulations are discussed below. Because live simulations do not have noteworthy commercial interest, they are not discussed here.

Constructive Simulation

Commercial simulation software has for the most part been concerned with constructive simulations in manufacturing, design of communication networks, and a wide variety of other application domains. For example, using modern computer-aided design and manufacturing (CAD-CAM) software, one can create simulations of components and assemblies of automobiles, aircraft, machine tools, and other physical objects made up of pieceparts in order to experiment with alternative designs, to test functional performance, and to ensure that pieceparts fit together properly.

In recent years, there has also been an increased use of constructive simulation in medical applications, where powerful computers and associated application software can be used to create two- and three-dimensional renderings of human organs based on data obtained from X-ray and ultrasonic scanners.

Many simulations are written in general purpose languages such as the C programming language for numerically based science and engineering problems and Common LISP®, a language designed for manipulation of lists of symbols and used for applications that operate on symbolic representations in ways functionally similar to human thinking (artificial intelligence). Object-oriented extensions to these general purpose languages, C++ and Common LISP® Object System, enhance the power of the respective basic languages considerably, but they do not provide the full range of useful programming facilities that are available in today's specialized simulation languages and environments.

A wide variety of commercial simulation languages can be found on the market, ranging from highly specialized program generators (e.g., SIMFACTORY, COMNET) to languages providing general discrete event modeling facilities (e.g., GPSS, MODSIM, SIMAN). Environments for expert system development such as ART-Enterprise and ProKAPPA contain comprehensive facilities for knowledge representation and reasoning (Hayes-Roth et al., 1983). Simkit combines some discrete event simulation features with knowledge representation and reasoning. Neural networks (Hammerstrom, 1993) and genetic algorithms (Goldberg, 1989) for optimization have also appeared in commercial software packages.

Virtual Simulation

Virtual reality can be loosely characterized as a combined hardware and software system that allows users the capability to simulate any real or imaginary situation and to interact with it (Marefat, 1993). Virtual reality can be traced as far back as the work of Ivan Sutherland on the design of a head-mounted display, but much of the modern virtual reality work came about after the supercockpit work at Wright-Patterson Air Force Base. Depending on the application, virtual reality has also been referred to as immersion simulation, virtual environments, telepresence, and artificial reality. About 50 small companies are in the business of developing the components to support virtual reality for business, training, and entertainment applications. Such components include: (a) input devices for sensory feedback such as head-mounted position trackers, data gloves, joysticks, keyboards, and body suits; (b) computer elements, including high speed graphic processors and data managers; and (c) output devices, including monitors, audio, and head-mounted displays.

Large companies, such as Lockheed and Boeing, are also involved in virtual reality through the development of software environments to support virtual reality-based simulations. Such environments must integrate (a) visual elements involving geometric models and their appearance; (b) auditory and tactile elements (although such capabilities are still in early stages, the integration of the visual, auditory, and tactile sensory information is critical to true immersion sensation); and (c) behavior models. The difference between computer animation and virtual reality is that virtual worlds are interactive (i.e., the objects in the virtual worlds move, react, and are affected by external events) (Marefat, 1993).

Recently, the focus of virtual reality research has started to move rapidly toward entertainment, engineering, and medical applications of interest to the entertainment, industrial and architectural simulation, and health care communities. Research into telepresence, in which the user is projected into remote environments through sensor/actuator interfaces, is accelerating both in academia and in potential commercial applications involving hazardous operations.

Trends in Commercial Development

Commercial systems are moving toward support of integrated modeling and simulation following many years of academic research (Oren and Zeigler, 1979; Henriksen, 1983). Such systems provide support for the model development process in addition to the run-time execution facilities provided by current simulation languages. The tools of artificial intelligence and knowledge-based systems are used to support aspects of the simulation enterprise (Balmer, 1986; Murray and Shepherd, 1987; Reddy et al., 1986; Rozenbilt et al., 1990). Fundamental requirements for standardized simulation environments have been formulated (Tanir and Sevinc, 1994; Zeigler et al., 1994). The various kinds of support are illustrated in Table 3-2.

Although none of the existing systems can satisfy all of the requirements implied by Table 3-2, Object-Oriented Knowledge-Based Simulation Environments

TABLE 3-2 Simulation Support

Various Kinds of Support for Simulations
Software Development Support
Enhanced model quality integral through development process
Comfortable prototyping/development/reification
Stand-alone modules
System composition from components
Top-down design/bottom-up testability
Configuration management
Visual interface access to environment
Output analysis, visualization, animation
Integration with virtual reality immersion
Model-Database Management
Integrate with standard database management systems
Support hierarchical synthesis process and model object hierarchies
Exploit model components resident in a model object base
Support organization and reuse of objects and models
Model Specification/Execution Simulation
Support continuous, discrete event and related dynamic system formalisms
Support artificial-intelligence knowledge representation formalisms: goal planning, rules, frames
Support multiple concurrent agents
Support model evolution through hierarchical, modular construction Stable real-time simulation
Model-to-Architecture Mapping Support
Support mappings of models onto diverse computer architectures
Facilitate upgrading to higher capability platforms through software compatibility
Assure correct simulation process
Generate alternative architectures and mappings
Experiment with/select efficient (time/space) alternatives
Support for Multiple Resolution Levels
Refine models to provide high fidelity representation
Coarsen models to meet execution time and space constraints
Integrate into the model base via abstraction mechanisms with explicit links for state and parameter databases.
Cross-validate models with respect to other (high or low resolution) models

SOURCE: Zeigler et al., 1994.

come closest to meeting them (Zeigler, 1990; Ruiz-Mier and Talavage, 1989).

BUILDING BLOCK TECHNOLOGIES

(Layer VI—Management/Security)

Building block technologies discussed under Layer VI—Management/Security of the generic architecture (Figure 3-2) include security technologies; network management systems; and general purpose languages, tools, development environments.

Security Technologies

Security is a major issue and a major concern among all providers and users of information networking applications and services. In the United States, privacy is one of our most cherished rights, and privacy concerns are a major impediment to successful realization of the vision of a national information infrastructure. Health care providers and patients are concerned about the protection of patient-identifiable patient records. Educators are concerned about the unauthorized disclosure of student records and also about the uncontrolled or unauthorized access of students to pornographic materials. Individuals do not want their messages and real-time communications to be disclosed, nor do they want information about their buying habits, what they read, their tax records, or other personal information to become available without their permission. Electronic commerce cannot flourish without the ability to conduct secure transactions and protect intellectual property from unauthorized uses.

Security includes:

- Protection of stored information or information in transit through a network from unauthorized access in usable form (eavesdropping);
- Protection of stored information or information in transit from unauthorized modification;
- Authentication that what has been received over a network has not been modified, and that the source of the information is who he or she claims to be;
- Protection of resources from unauthorized access;
- Protection of users' identities from those who are not authorized to know their identities;
- Protection of information about users' usage patterns: what they access, how often, from where; and
- Protection against denial-of-service attacks that prevent authorized users from accessing resources and information when they need to do so.

Recent trends in commercial systems and applications have been to enhance security. There is a tradeoff between the level of protection that can be provided and the ease with which legitimate users can use the services they are authorized to use. This tradeoff is shifting in time as advances in technology are making such things as powerful smart cards available. Standards are the pacing factor here, because the industry recognizes that users will not wish to carry around a variety of different types of smart cards for different purposes. Thus, much effort is currently being employed to identify the broad range of applications and the corresponding capabilities that must be embedded in smart cards. Smart cards are essentially credit-card-sized miniature computers that contain secret encryption keys, the ability to execute security (encryption) algorithms, and input/output capabilities to interface with terminals or appliances. They can store personal information such as medical records, and they can also be loaded with electronic money.

To illustrate the trends in commercial practice, one can consider the following examples.

First-generation cellular networks are relatively susceptible to eavesdropping. Next-generation digital cellular networks will employ encryption techniques to make eavesdropping more difficult. Emerging wireless personal communications networks will, in some cases, employ spread-spectrum code division multiple access (CDMA) techniques and even more powerful encryption algorithms. These networks may also employ public key cryptography algorithms to allow accessing users to authenticate themselves to the network without disclosing their identities to eavesdroppers. CDMA systems are not only intrinsically eavesdrop-resistant but also resistant to direction finding because their low-power signals are spread over a broad range of frequencies, which are shared by all other users.

When remote users log on to their host terminals over networks, there are opportunities for passwords to be compromised to eavesdroppers, particularly with wireless networks. This has led to the use of special credit-card-sized tokens that generate and display pseudo-random numbers that are used as one-time passwords. Using a variety of approaches, the passwords generated by these tokens can be authenticated by host security systems that know the secret information residing in the token that generates the passwords. Eavesdroppers cannot make use of these passwords after their initial use by authorized users. The use of these single-purpose tokens may be eliminated when their functionality is absorbed into general-purpose smart cards in the future.

Standards for digital signatures, based on public key cryptography, make it possible to not only verify the source of a piece of multimedia information that has been stored or transmitted in digital form, but also to validate that no change has been made to the digital multimedia object subsequent to being signed by the originator. Extensions of this approach have resulted in the ability to also authenticate the exact time that a document was signed (digital notary service) in ways that are acceptable in legal settings.

In general, cryptography makes it possible to make multimedia information inaccessible to unauthorized users by placing it in a form that is not usable without the secret cryptographic decoding key. Commercial methods for implementing cryptography are widely available, although export restrictions, difficulties in negotiating terms with respect to the use of patented methods, and certain federal government initiatives with respect to encryption methods, which contain "back doors" to allow government access under specified circumstances, have temporarily hampered progress in converging on commercial standards for strong encryption methods.

There are initiatives under way to create cryptographic methods to support electronic commerce, including the exchange of credit information over public networks. Several vendor-specific approaches are currently being employed in commercial networks to support electronic shopping and the sale of intellectual property over networks.

Firewalls to prevent attacks on network enclaves (i.e., networks within a specified administrative domain, such as those of a company or a university) from determined intruders are available and are continually being upgraded as more sophisticated attacks are developed and employed. Applications exist for automatically detecting network security vulnerabilities against known attacks due to improper configurations of networks and their attached hosts. However, protection of networks against determined attackers remains on ongoing problem for commercial and institutional system administrators. It has been described as a journey, rather than a destination, where the objective is to minimize risks and to detect quickly and limit the damage associated with attacks.

In summary, with network and information security as one of the pacing factors in the successful realization of the applications associated with a national information infrastructure, which represent a commercial market opportunity measured in hundreds of billions of dollars per year by most estimates, there is a very large commercial R&D effort under way to create, standardize, and deploy easy-to-use, powerful, and inexpensive security technologies and methodologies.

Network Management Systems

Network management systems are used to manage large, distributed, heterogeneous information systems. Management functions range from authorizing users to have access to specific services and applications to recovering from faults or attacks. Typically, management is accomplished in a layered fashion to make the management process itself manageable. Individual network components such as communications nodes (e.g., switches, multiplexers, routers) and links (e.g., fiber optic systems), servers, and end systems contain self-diagnostic functionality and the ability to remotely configure or reconfigure their capabilities.

The network management functionality that is devoted to monitoring and controlling these individual components is referred to as residing in the *element management* layer. Collections of components work together to perform such functions as the provision of communications paths or accessible databases. While individual components may fail, redundancies can make it possible to maintain these functions. For example, a communication path can be maintained by using an alternative route through a multiconnected network. A backup server can be used to take over for a damaged server. The network management layer that is responsible for maintaining such things as communications paths and database capabilities is known as the *resource management* layer. Higher layers in the network management stack are responsible for providing specific types of services and applications to specific users and user classes.

As distributed, multipurpose, multiprovider, heterogeneous networks have proliferated in the commercial world, network management has become a major commercial market. Downsizing and reengineering of commercial firms and industries have placed ever more importance on the elimination of manual tasks and the use of automated systems to configure, troubleshoot, and control networks. The increasing dependence of society on information networks in such areas as commerce, health care, and air traffic control places a premium on reliable systems that can quickly control and isolate problems.

General Purpose Languages, Tools, Development Environments

Any piece of computer software, whether used in an operating system, a multimedia database, multimedia teleconferencing software, or a network management system, is a program. Any such program, in turn, must be written in a programming language. While the programming language in which software is written may be unimportant to a user of an application embodied in a program, if the software is to be extended, modified, or customized, the programming language in which this is done becomes critically important.

Early computer programming languages such as FORTRAN were designed primarily for numerical calculation and were aimed at freeing the programmer from having to consider the details of a computer's hardware when writing a program. Modern computer programming languages such as C++ and Ada were designed to support a spectrum of application domains. They also recognize large-scale software development as a continuing group process involving many individuals and thus support widely recognized software engineering principles: (a) programming is a human activity, and (b) software should be maintainable, portable, modular, and reusable.

Hundreds of computer programming languages have been developed, and yet only a relatively small handful have found widespread use. Rather than provide a comprehensive survey of languages, the committee examines here two of the most important languages in use today for application programming and system software development: Ada95 and C++.

Ada traces its birth back to 1975, when the Department of Defense (DoD) established requirements for a high-level language that could be used in all defense projects. In 1976, 23 existing languages were formally reviewed and none were found to meet the requirements. It was concluded that a new language was needed, and the Ada language was born. Ada became an American National Standards Institute (ANSI) standard in 1983 and an International Standard Organization (ISO) standard in 1987. The 1983 Ada standard was updated in early 1995 and, like the original Ada, is intended for embedded and real-time systems. It also has a number of built-in features to support distributed computing. A major improvement found in Ada95 is its support for object-oriented programming and enhanced support for real-time systems.

The so-called "Ada mandate," Public Law 101-511 Sec. 8092, states that Ada should be used for all DoD software: "Notwithstanding any other provisions of law, after June 1, 1991, where cost effective, all Department of Defense software shall be written in the programming language Ada, in the absence of special exemption by an official designated by the Secretary of Defense." Thus, Ada has considerable visibility within the defense contracting industry. The extent to which Ada is used in non-government-sponsored software development is the subject of continual debate. Numerous commercial uses of Ada are documented (IIT, 1995).

C++ is another modern general-purpose language of roughly similar power to Ada. It is object-oriented and also has many features that modern software engineering practice considers important. It is a descendant of the C programming language, which was developed in the early 1970s at Bell Laboratories, and has found widespread use since then. Standardization efforts are underway in both the ANSI (American) and ISO (International) groups to develop a C++ standard. It has been stated that C++ is by far the most popular object-oriented programming language and that the number of C++ users is doubling every 7.5 to 9 months. Trade magazines contain numerous reviews of compilers and development environments for C and C++, thereby attesting to the widespread interest in this language.

Associated with these languages are a number of tools and development environments. These are attempts to ease the programming task, organize teams of programmers for large projects, and "debug" programs effectively. Examples of such tools include syntax-directed editors, source-code control systems, and symbolic debuggers.

A syntax-directed editor provides programming language syntax checking and language-specific structuring as the program is typed in by the programmer. The advantage of this approach is that many of the "bugs" common in early stages of program development can be eliminated before the first trial compilation of the program.

Systems for controlling source code, such as the Source Code Control System (SCCS) and Revision Control System (RCS), serve as repositories for the source code comprising a program. There are facilities provided for change management, which is critical in management of large-scale software projects.

Symbolic debuggers allow a failed program to be analyzed in the form of the symbols used by the programmer to write the program. The advantage of this technology is that the programmer is able to more quickly isolate conceptual errors because the form of the error report is in the semantic structures used by the programmer rather than those of the lower-level "object code" used by the machine.

SYSTEMS

In this section the committee gives examples of system-level applications of multimedia information technology existing or emerging in the commercial domain. These examples will provide substantiation for the recommendations in Chapter 4 as to which building block technologies the Army should adopt or adapt from the commercial domain and which building blocks are candidates for Army-specific development to produce proprietary advantages over its adversaries. This section covers four major systems: cellular and wireless, electronic commerce, intelligent transportation systems, and residential information services.

Cellular and Wireless Telecommunications Systems

Revenue growth and subscriber growth in cellular systems have exceeded even the most optimistic projections of its early proponents. Yearly revenues in North America have grown from $500 million in 1985 to over $4.6 billion by year-end 1993 (Leeper, 1995). This is an average annual revenue growth of 32 percent. Revenue growth rates are retreating slightly but are still expected to exceed 20 percent annually through 1996.

Globally, in 1993 alone, the number of subscribers went from 21.1 million to 33.1 million, a growth of 56 percent. In North America, the growth was 47 percent, going from 12.1 million to 17.7 million (Leeper, 1995). Note that revenues are not growing as fast as subscribers because of declining prices.

With more advanced electronic, battery, and antenna technologies, there has been a marked move toward personal, portable handsets. In 1987 only 5 percent of handset sales could be called "portable"—vehicular sets accounted for 78 percent of all sales, and "transportable" units 17 percent. In 1993, portable sales had jumped to a 36 percent share of the total, transportables to 35 percent; vehicular sales had declined to 29 percent of the overall market (Leeper, 1995).

Prices on cellular subscriber units have dropped to well within the means of mass market consumers. In 1993, portable units in the United States had an average "walk-away" price of $343 with some units sold for as little as $43. Vehicular units averaged $264 and transportables $187. Despite their higher average price, portables remain the fastest growing segment of the market (Leeper, 1995).

Customers appear willing to pay a premium for portability and convenience, and technology has made very small and lightweight phones possible. The leading handset manufacturer has recently introduced a "flip-phone" model weighing only 3.9 ounces. The phones are becoming as small as is practical for human fingers to operate; further reduction in size may require a paradigm shift in packaging and other means of input and output.

Since it is still inconvenient in many circumstances to "wear" a phone and to answer it every time it rings, many users today wear a vibrating pager and use it to screen calls. The portable cellular phone stays in the briefcase until it is actually needed. This practice portends the day when a person may "wear" a personal, wireless, LAN (local area network) that links a pager, phone, and PDA.

Cellular and wireless users, particularly business users, are increasingly demanding more reliable, secure, nearly ubiquitous service with the ability to move around freely. They are demanding lighter, more reliable handsets with longer operation between battery charges. They are also demanding multipurpose units that can operate as cordless telephones, cellular telephones, and telephones that can access emerging personal communication networks.

Electronic Commerce

Electronic commerce refers to the conduct of business using distributed information networks that connect geographically distributed locations of the same firm, firms and their suppliers, firms and their customers, and multiple firms jointly creating and marketing products.

The banking industry is at the leading edge of electronic commerce in its use of information networks to conduct billions of dollars of transactions on a daily basis. The banking industry uses information networks to move money among accounts distributed worldwide and to monitor critical information needed to make financial decisions, such as the granting of loans and lines of credit. These networks are also used to collect and process credit and debit card information from hundreds of thousands of merchants who accept these cards, to clear hundreds of millions of checks on a daily basis, and to operate automatic teller machine networks on a worldwide basis.

All major stock exchanges depend upon information networks to conduct hundreds of millions of trades each day. This dependency has become increasingly evident during recent outages at the NASDAQ exchange.

For more than a decade, electronic data interchange (EDI) has been used between firms and their suppliers to place orders, send invoices, and make payments on accounts payable. Some large firms will not deal with suppliers who cannot conduct their business using EDI.

Recently, there have been successes in various forms of electronic shopping (e.g., the Home Shopping Channel), and this success is fueling the emergence of on-line shopping services over which purchases can be transacted. Such transactions may involve the use of credit cards, debit cards, electronic checks, or anonymous electronic money.

In all of these existing and emerging applications, network integrity, network reliability, and security are major, ongoing concerns. Not only are these networks susceptible to theft of services, fraud, compromise of private information, and attempts to steal or counterfeit electronic funds, but they are also susceptible to disruptive attacks and accidents that can cause billions of dollars per day of economic damage.

Intelligent Transportation Systems

Departments of transportation at the federal and state levels have concluded that it will be increasingly difficult, if not impossible, to construct new roads to accommodate increasing traffic loads over the next several decades. Meanwhile, there is a need to increase highway safety, to improve traffic flows to decrease congestion resulting from accidents and stochastic traffic surges, and to track the locations of commercial and public vehicles. In response to this realization, an initiative known as Intelligent Transportation Systems (ITS, formerly known as Intelligent Vehicle/Highway Systems) has been established.

Consensus estimates are that government and private investments in ITS cumulatively up to the year 2011 will be $210 billion (IVHS, 1992). In fiscal year 1995, the U.S. Department of Transportation budget includes $227.5 million in funds allocated to ITS research and development, operational tests, and other ITS-related initiatives and applications. These applications include highway sensors (including cameras) that will monitor traffic and send traffic information over wireless and wired communications networks to centralized traffic control nodes; traveler information systems that will distribute traffic reports to travelers in automobiles, trucks, and their homes and offices; positioning systems that will allow vehicles to track and report their locations to centralized nodes; 911-emergency systems that will allow travelers to report problems, including their precise locations (currently a serious problem in cellular emergency calls); map delivery systems that will guide travelers to their destinations; and others that are less relevant to this report.

These distributed systems and their associated appliances and applications will have to be reliable, secure, easy to use, and affordable in mass market applications.

Residential Information Services

In 1994 the sales of home-based personal computers equaled that of television sets ($8 billion) (Markoff, 1995). It is anticipated that, over the next decade and beyond, the use of residential multimedia computers to access information (education, health care, personal finance) and to shop for and purchase information and consumer products will become commonplace. In order for this vision to become a reality, residential applications must be intuitive and easy to use. There is an increasing awareness in government and industry that universal service will not be solely a matter of financial means but also a matter of the usability of information services and applications by those members of society who are not technologically oriented and have limited time to invest in learning how to use new technologies. Thus there is an ongoing, major R&D effort to achieve increasingly user-friendly graphical (and other) user interfaces and so-called plug-and-play capabilities.

For example, there is a large amount of commercial activity related to the design of set boxes for interactive multimedia applications in the home. The terminology "set top box" refers to a piece of equipment, used in conjunction with a standard television set, which acts as an interface between an interactive or noninteractive multimedia communication service—being provided via a coaxial cable, a pair of copper wires, a satellite or terrestrial microwave antenna, or an optical fiber—and the standard antenna input of the television set. The set top box may contain powerful processing and information storage capabilities, and it may provide a sophisticated user interface that allows the user to do such things as navigate menus of available programs and other information and to interact with the application the user has selected. Much of this current activity relates to the design of a user interface that is easy and intuitive to use for the more than 95 percent of the general population that owns television sets. In addition, since the upstream (user-to-network) bandwidth is very limited in many architectures for connecting end users to the information servers that provide multimedia to these set top boxes, yet the response time to user requests (e.g., program changes) must be very short, there is a big emphasis on maximizing performance in the context of bandwidth limitations.

LESSONS LEARNED IN THE COMMERCIAL WORLD

The major focus of this section is on lessons learned in the commercial world in the application of multimedia information technologies. These lessons support the committee's recommendations that appear later in this report. The following sources of lessons learned will be addressed: architecture, standards, vertical versus horizontal structures, leveraging commercial off-the-shelf (COTS) technology, how business meets special technology requirements, leveraging legacy investments and fostering rapid acceptance of information technology, and adopting a spiral model of development.

Architecture

Because we can observe its entire life cycle, the IBM System 360 serves as an excellent case history from which to draw a few essential lessons about architecture.

In the late 1950s and early 1960s, IBM was facing a problem. IBM was fielding an ever-widening variety of systems, few of them compatible with one another and each separately optimized for a particular set of applications. Further, each system required a separate training regimen for IBM's field support staff, leading to very high maintenance costs.

To solve the growing problem, IBM's executives commissioned the design of a single, logical architecture from which an integrated family of systems could be built. The result was the now famously successful System 360 (and its follow-on, System 370) family of systems.

> What are the lessons to be learned from this successful commercial experience with architecture? Fred Brooks, System 360 Development Manager, says (Brooks, 1975):System 360 architects had two almost unprecedented advantages:enough time to work carefully, and political clout equalto that of the implementors. The provision of enough time came from the schedule of the new technology; the political equality came from the simultaneous construction of multiple implementations. The necessity for strict compatibility among these served as the best possible enforcing agent for the specifications.
>
> Regarding the architecture design, Brooks writes:
>
> I will contend that conceptual integrity is "the" most important consideration in system design. It is better to have a system omit certain anomalous features and improvements, but to reflect one set of design ideas, than to have many good but independent and uncoordinated ideas. Conceptual integrity does require that a system reflect a single philosophy and that the specification as seen by the user flow from a few minds.

The principal lessons here are that creation of a communications and computing architecture requires that (a) a few resonant minds create the architecture, (b) they be given time to work, and (c) the architecture be enforced not only by edict but also by simultaneously constructing several of the system implementations that use the architecture.

The committee notes that cultural separations among existing functional groups, profit centers, divisions, etc., exist in all commercial companies and other institutions. Pride and esprit de corps within these are typically long-standing and well cultivated, and they typically have produced very positive results in the past. Unfortunately, they are also major obstacles to developing an integrated "enterprise" or "information" architecture. The challenge is to overcome these obstacles by taking steps like those taken at IBM in the context of system 360. Such successes are, to date, quite rare.

Standards

The commercial world places great value on the existence and widespread use of standards. Standards consist of sets of rules with which conformance to the standard can be evaluated. These rules can be applied at many layers in systems, ranging from physical connectors to the graphical user interfaces discussed elsewhere in this chapter.

Standards have the business advantage that, once defined, all commercial enterprises that wish to compete for the provision of components of an integrated system can exploit whatever competitive advantages they possess or can create without having to be vertically integrated suppliers of the end-to-end system. Thus, standards are pro-competitive. The consumer derives advantage from the fact that technologies adhering to a standard are interoperable. Interoperability means that one of a set of interoperable components can be procured or upgraded independently of others. For example, all compact disc players use the same compact disc, although significantly different sampling schemes and signal processing technologies can be applied, resulting in a variety of consumer choices, from low quality to audiophile quality.

Industry standards emerge in two ways, which can be interrelated and often are. First is through the use of a standards body. The purpose of the standards body is to provide an impartial design and selection of a standard. The most effective standards bodies rely on groups of technical experts in an area to define a useful and effective standard. Examples are the Institute for Electrical and Electronics Engineers (IEEE), the International Standards Organization (ISO), and the ATM (Asynchronous Transfer Mode) Forum. IEEE Standards usually relate to computer and communications devices and their functions. Examples include standard formats for computer representation of floating point numbers (IEEE 754) and standard interfaces for a portable operating system (IEEE 1003, POSIX).

ISO standards include the Open Systems Interconnect standard or OSI; this standard defines a multilayer protocol model which was carefully defined and accepted as a standard before implementation was begun. This latter case illustrates a risk with standardization by committee. The risk is that the committee will be bypassed with a second form of standardization, the de facto standard based on user preference. In the case of OSI, implementation of the Internet protocol described earlier in this chapter proceeded without a complete formal standardization process, and yet it has become the de facto standard for Internet communications.

De facto standards are a result of market dynamics. If a clear standard is not established when a company wishes to enter a market, it can either wait for a standards body to put forth a standard to which it will adhere, or it can take its own approach and presume that it will achieve sufficient market share to become one of a small set of accepted solutions. An example where this has occurred is in the design of command sets for asynchronous modems, where a manufacturer (Hayes) developed a command set that is a de facto standard. Such standards are sometimes developed as a byproduct of other competitive advantages possessed by a company. In the Hayes case it was a flexible microprocessor-augmented modem called the SmartModem®, which was a huge commercial success; the Hayes command set has outlived the company. Once established, such standards are violated at considerable commercial risk.

Official standards and de facto standards can be the same if the official standard is available early enough so that companies see an advantage in adhering to it, or if the de facto standard becomes officially recognized by a standards body. The former case is exemplified by the ATM Forum, which specifies standards for a variety of protocol layers in ATM networks. The latter case, while pragmatic, can be fraught with difficulty as the company that originated the de facto standard may be given a further advantage by ratification of its technology as a standard. Standards bodies have traditionally been reluctant to ratify a situation that might, by giving advantage to a particular vendor, give the appearance that they may not be impartial, although recently there has been a trend toward the adoption of de facto standards by standard forums like the Open Software Foundation.

Companies address their concerns with standards by becoming active participants in standards bodies when technological standards may affect them or be positively influenced by their input. Companies put their concerns into the deliberative process of the standards body. For example, computer manufacturers were highly influential in the design of the ATM Adaptation Layer 5 standard, which allowed for overlapped operation of check-sum computation and data movement that is highly desirable in computer networking environments.

Vertical Versus Horizontal Industry Structures

In the first several decades of its existence, the computer industry was vertically integrated. Each firm (e.g., IBM, Digital Equipment Corporation) designed, developed, and sold all of the hardware and software needed by its customers to implement their computing applications. In the past 15 years, the computer industry has assumed a horizontal structure. Intel, Motorola, and others make microprocessors and memory chips. Compaq, IBM, Apple, and many others make personal computers and a wide variety of plug-in boards and peripherals. Microsoft, IBM, Apple, and others make operating systems. A large number of firms sell middleware and application software (The Economist, 1993).

The transition to a horizontal structure has been driven by several factors. Customers demanded open system solutions that would allow them to mix and match products from multiple suppliers; this necessitated the opening of interfaces, which allowed competing firms to sell horizontally structured products. Economies of scale and a very competitive marketplace made it necessary to focus on one's core strength and to sell into as large a market as possible.

This same transition from a vertical structure to a horizontal structure is affecting many other industries. Global competition is causing firms to focus on their differentiating advantages and to outsource what they can get better or cheaper from others. For example, an airline may determine that its reservation system should be a separate business rather than a vertically integrated part of a business that includes the component that actually flies passengers. The airline may also outsource its maintenance and meal preparation service. It is not clear that each airline needs to maintain its own baggage handling staff. What to keep and what to outsource is a critical decision regarding where one wants to differentiate from competitors.

In the long distance telephone industry, competing firms have been differentiating themselves via the capabilities of their billing systems to support complex discount plans. It is conceivable that someday telephone companies will outsource their networks and differentiate themselves on the basis of marketing and customer support services.

A lesson learned is that to achieve superiority (beat the competition) in information-technology-intensive businesses, one should focus development efforts on areas where one intends to achieve a differentiating advantage and should outsource everything else.

Leveraging Commercial Off-the-Shelf Technology

The commercial telecommunications industry is one of the largest consumers of multimedia information technologies. It is therefore useful to examine recent trends within the telecommunications industry in leveraging COTS multimedia information technologies. Much can be learned from successful companies in this industry.

For example, MCI and SPRINT, two of the largest providers of inter-exchange ("long distance") telecommunications services ("carriers") in the United States, conduct only limited R&D activities. They focus on defining the overall architectures of the networks they wish to deploy, the associated management systems, and tracking technology trends. They carefully determine how they wish to differentiate themselves from their competitors (e.g., in such areas as billing systems and customer service), and they commission the development of those differentiating capabilities using commercial-off-the-shelf technologies (i.e., they focus on implementing applications of commercial off-the-shelf technologies, not the underlying technologies themselves).

The providers of cellular telecommunications services have relied on their suppliers to produce innovations in technology, while they (the providers) have focused on applying that technology in their networks. When members of the cellular telecommunications industry determine the need for a new capability (e.g., inter-network signaling to enable nationwide roaming), they call upon their supplier community to produce proposals for how this might be implemented. Cable television companies follow a similar strategy to that of the cellular companies, maintaining only a modest R&D effort focused on defining requirements for new system architectures and capabilities.

Recently, the local exchange carriers (Ameritech, Bell Atlantic, and others) have been moving their R&D focus more toward applications of technology and differentiation from their competitors—based on lower cost structures and superior customer service enabled by the skilled application of commercial-off-the-shelf technologies obtained from their suppliers. They are placing less emphasis on investing in the creation of the underlying technologies themselves and are relying instead on their suppliers to make those investments. However, they do spend considerable effort in understanding technology trends in order to anticipate both opportunities and competitive threats that might result from lower costs or new capabilities enabled by advances in underlying technologies in all of the layers of the generic technical architecture described earlier in this chapter.

In the telecommunications marketplace, a specific example of this approach involves the introduction of new fiber optic systems based on Synchronous Optical Network (SONET) standards. These systems are more cost-effective and more easily reconfigured than the prior generation of fiber optic systems. The supplier community produces these systems and makes them available to all carriers. The carriers focus on applying these systems in their evolving network architectures to reduce their costs and to obtain the benefits of more flexible and reliable networks. Where carriers attempt to differentiate themselves is in the use of management systems that allow them to be more responsive than their competitors in filling orders for new services that are carried on their networks and in quickly responding to service interruptions caused by cable cuts and equipment failures.

How Business Meets Special Technology Requirements

Business tends to solve problems using as much commercial technology as possible, since business is loathe to engage in R&D to solve immediate problems. It is worth studying an example in detail to understand the approach. A major investment bank, Morgan Stanley, needed a system to support trading operations in its New York City trading areas. The reliability requirements of the system were extremely high.

The Morgan Stanley approach to this problem was at the system level (i.e., a system of systems to provide high reliability using commercial components). In this case, the commercial systems were redundant engineering workstations connected by dual Ethernet LANs. System software was written to automatically reroute work and network traffic in the case of failure. Thus the system was created from commercial technology using redundant commercial components in a nonstandard way. The nonstandard result was almost exactly twice as expensive, but it achieved a multiplicative gain in reliability for this cost plus the addition of a small amount of software and some management discipline.

Thus a somewhat ad hoc and opportunistic approach led to a solution that met Morgan Stanley's needs via the innovative application of COTS technologies. The key to success was in focusing on meeting the need, while leaving the solution (detailed requirements) flexible.

Leveraging Legacy Investments and Fostering Rapid Acceptance of Information Technology

Corporations and institutions have been deploying computer based systems and applications for 40 years. These systems are based on a wide variety of diverse technologies and architectures and were typically not designed to interoperate with each other in the context of an overall enterprise-wide architecture. Collections of such systems, which represent an embedded investment by the organization or enterprise, are typically referred to as "legacy systems." The issue of "what to do with legacy systems" is an old one in the commercial world, but it is growing in importance as the number and complexity of legacy systems increase and as the accompanying maintenance costs and update backlog grow. In addition, the allure of more modern systems with updated technologies has made the weaknesses of legacy systems more prominent.

The technical problem of designing a new system to replace a legacy system is usually the easiest part of a problem. Much more difficult is the cost justification of replacement, management of risk (at first, the new system might not work as well as the old), and reluctance of users and system operators to learn the way a new system works. On the other hand, most engineers prefer to work on new-systems design rather than upgrading old systems, and legacy-system expertise becomes more and more scarce as time goes by.

While there is no single preferred method of dealing with the legacy system dilemma, the following are suggested alternatives.

Alternative 1

The first alternative would develop a new-technology, wholesale replacement for the legacy system, with no change in functionality or user interface. This approach has the advantages that the requirements may be well understood (see below) and there is minimal retraining for end users. Ostensibly there will be attractive future savings in maintenance costs, and the new system will accept upgrades more quickly and gracefully.

The difficulty is that, in any given year, it is always cheaper to carry the legacy system a bit further than to undertake a new development. In addition, all of the requirements that are being met by the old system may not be well documented. Therefore, the new system may initially fall short of meeting all current business requirements. In addition, for large systems, such "big bang" approaches to the replacement of legacy systems have almost always failed to meet schedules and budgets and have often resulted in major project failures where hundreds of millions of dollars of development have been "written off."

Alternative 2

This alternative would develop a new-technology replacement for the legacy system, with new features and capabilities. This approach is similar to alternative 1 above, except it has the additional advantage of offering new features that may answer long-standing requests for legacy system upgrades. Such new features may add risk, delay, cost, and new user-training requirements.

Alternative 3

The third alternative would freeze changes to the legacy system and "surround" or encapsulate it within a new system. Over time, legacy system functions can be replaced by new-technology elements until the legacy system is totally replaced. This approach has the advantage of leveraging capabilities already present in the legacy system without making further direct investments in it. It has the disadvantage that few legacy systems can be subsumed easily within a new system.

An example of this approach is to make existing legacy system data accessible via modern graphical user interfaces, which can access multiple legacy systems and new systems in an intuitive, easy-to-use manner. This approach has been successfully employed to transition large legacy systems used to manage and automate telephone company operations.

Alternative 4

The last alternative would (a) continue to use and maintain a legacy system but "cap" the number of users, and (b) develop a new system for new users (or some subset of the old users) and develop interworking arrangements with the legacy system as required. This approach has the advantage of limiting the expansion of the legacy system while simultaneously limiting the risk associated with wholesale replacements. If the new systems truly offer lower costs and increased capabilities, then it becomes easier to plan for the legacy system replacement because the benefits will be known in advance. This approach has the disadvantage that it may not be appropriate for large, tightly integrated systems. In particular, the interworking problems with the legacy system could be substantial.

Deciding which path to pursue is ultimately based on such things as cost-benefit trades and the culture of the organization facing the problem. In any given budget-year, it is almost always cheaper and politically safer to "get one more year" out of a legacy system than to attempt replacing it. Alternatives 3 and 4 above can be used to control risk, but ultimately it takes farsighted managers who encourage risk taking by subordinates to pursue a legacy system replacement program.

Adopting a Spiral Model

In recent years, industry has moved from its traditional model of software development, sometimes pejoratively referred to as a "waterfall" model, to a new model of software development referred to as a "spiral" model (Boehm, 1987).

In the traditional waterfall model, development proceeds in one sequence through the following phases: system requirements specification, system design, software coding, and system testing—with any problems found in system testing generally repaired by iterating back to the design or coding phases. The waterfall metaphor derives from the one-way flow of this process down a sequence of, for the most part, irreversible steps.

The difficulty with this process is that, in complex systems, requirements that are set early on may not adequately capture the needs of real users. In addition, some requirements may imply development difficulties and corresponding costs that are out of proportion to their user benefits. Those who formulate the requirements may not be aware of the latest emerging technologies and their associated or potential capabilities, and thus they may specify requirements that cannot leverage these capabilities. As a result, large systems may be developed that fail to meet user needs, take longer to develop, and are more costly than necessary.

To address this problem, a "spiral" model of development has been adopted by most developers of large, complex software systems. In the spiral model, one iterates quickly through a cycle of requirements specification, development of a prototype that captures the most important aspects of the requirements (prototyping), and testing with real users. In this iterative process, one can quickly discover user needs that are not met (e.g., the system is hard for real users to use), and one can quickly discover requirements that drive cost and total development time out of proportion to their intended benefits. The spiral metaphor derives from the rapid cycling that occurs through the phases of requirements specification (and respecification), prototype development, and testing.

Experience shows that the spiral model of development leads to lower development costs, more rapid development, and substantially greater satisfaction of real user needs. Key to this process is the use of prototypes that simulate the most important aspects of the system under development but do not implement all of the detailed requirements on each cycle through the spiral model. As an illustration, an early mock-up of a user interface could be done with something as simple as Post-it® notes stuck on a board to simulate pull-down menus. A simulation of a database access capability need not be connected to the real database system. It could, instead, be connected to a simulated database system that imitates the delays that will occur in returning an answer to a query and illustrates how the answer will be presented to the user.

Process Improvement

For all its importance, the production of software, especially large-scale system software, is still as much art as it is science. To address the problem, the Software Engineering Institute (SEI) of Carnegie-Mellon University developed a Capability Maturity Model for software organizations wishing to improve their proficiency (Humphrey, 1989). The approach provides an explicit road map for change and a way for an organization to keep score on its progress.

Specifically, the SEI Capability Maturity Model allows an organization to rate itself and track its progress through five successive "levels" of proficiency. Level 1, the lowest level, is characterized by chaos and unpredictability in cost, schedule, and quality. Level 5, the highest level, is one in which cost, schedule and, quality have become highly predictable based on quantitative, repeatable measurements and well-established procedures. The intermediate levels allow an organization to track its evolution toward Level 5. The SEI Capability Maturity Model has become well-established in the software industry. Most large software organizations conduct self-evaluations, and many are evaluated by outside consultants who specialize in doing so.

The approach the SEI took is quite general—it is based on the writings of P. B. Crosby and the "quality maturity structure" that he defined (Crosby, 1979). The fundamental (and common sense) notion taught by Crosby is that an organization wishing to make a positive change in the way it does business "must" find a way to treat its processes as measurable, trackable, and controllable.

SUMMARY

This chapter has outlined commercial multimedia technologies to provide support for the analysis contained in Chapter 4. The principle was to examine building block technologies selected on the basis of a generic layered architecture, which was introduced at the beginning of this chapter. The intent was to describe each of these building blocks, with a focus on their current status and likely trends.

In addition, there was discussion of examples of commercial, system-level applications of multimedia technologies. Finally, there was a review of some important lessons learned in the commercial world with respect to these technologies.

This chapter has shown that multimedia information technologies and the capabilities they enable are evolving rapidly under the pressure of commercial market forces and underlying technological advances. This status portends well for the availability of solutions from the commercial world that will be addressed in Chapter 4.

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Meeting Army Needs with Commercial Multimedia Technologies

This chapter shows how the building block technologies of Chapter 3 can be used to meet the Army's operational needs described in Chapter 2 . First, the committee maps the building block technologies onto the operational needs and functional requirements. The technologies are also examined in the context of the multimedia architecture introduced in Chapter 3 as well as other architectures. The committee then assesses the prognosis for future development of the building block technologies and offers recommendations as to whether the Army should adopt commercial technologies, adapt commercial technology, or invest in producing its own technology when drawing upon the building block technologies to meet its functional requirements.

For additional clarity in how multimedia technologies can enhance the capabilities of the Army, the committee examines how battle command in a typical Army corps combat operation might be affected by the insertion of modern multimedia capabilities enabled by the building block technologies. The chapter concludes with an analysis of the operational example and how it relates back to the Army's operational needs.

MAPPING ARMY NEEDS TO BUILDING BLOCK TECHNOLOGIES

The building block technologies discussed in Chapter 3 are listed in Table 4-1. Table 4-2 presents the committee's view of how the Army's operational needs and functional requirements will be enabled by these building block technologies. The numbers in the third column of Table 4-2 refer to the technologies listed in Table 4-1. Note that most of the needs and requirements are enabled by a combination of two or more of the building block technologies.

Table 4-3 lists the building block technologies and the associated Army functional requirements they enable. From Table 4-3, it is clear that most building block technologies can be used to satisfy multiple operational needs and functional requirements.

One possible approach to meeting the Army's operational needs would be to develop individual information systems or domain-specific architectures to match each of the functional requirements. These systems could be designed and developed with commercial off-the-shelf (COTS) technology and made to interoperate through standard interfaces and data representations. While this approach may be preferred in some cases (e.g., because it offers an expeditious path to meet specific functional requirements), it does not take advantage of generic building blocks that could help satisfy several requirements (for example, see the discussion of middleware services in Chapter 3).

TABLE 4-1 Building Block Technologies

1.	Lightweight, rugged, portable appliances and terminals
2.	Storage systems for multimedia information
3.	Communications platforms that support people on the move
4.	Information capture technologies
5.	Protocols and related functionality to support communications
6.	Distributed computing environments and operating systems
7.	Information filtering systems
8.	Multimedia database management systems
9.	User-friendly multimedia user interfaces
10.	Multimedia information analysis and processing building blocks and middleware services
11.	Multimedia information access capabilities
12.	Decision support tools, groupware, multimedia teleconferencing
13.	Multimedia messaging capabilities
14.	Simulation: systems and applications
15.	Security technologies
16.	Network management systems
17.	General purpose languages, tools, development environments

TABLE 4-2 Summary of Army Operational Needs, Including Simulation, and Functional Requirements and Their Most Relevant Enabling Building Block Technologies

Army Operational Needs (Including Simulation)	Functional Requirements	Building Block Technologies[a]
A. Improved situational awareness	A1 Sensors	4
A2 Intercept capabilities	4,10	
A3 Accurate position location	4,10	
A4 Automated platform monitoring	4,10	
A5 Interconnected communications networks	3,5,16	
A6 Remotety accessed databases	2,3,5,6,7,8,11,16	
A7 Decision support aids	10,12	
A8 Scalable data	2,7,10,11	
A9 Flexible graphics	9	
B. Common, relevant picture of the battlefield	B1 Common distributed database	2,3,5,6,8
	B2 Ability to access database	2,3,5,6,11,15,16
	B3 Interconnected communications to transmit imagery, data, voice/selective access	3,5,11,13,15,16
	B4 "Eavesdrop" voice capability	3,5,11,12,15
	B5 Portrayed graphically/scalable/easily understood	8,9
C. Command on-the-move	C1 Reconfigurable software	6,17
	C2 Common hardware standards, protocols	1,3,5,6,17
	C3 Rapid operation/turn-on	1,3,5,6
	C4 Easily accessible networks	3,5
D. Improved target handoff	D1 Linkage of sensors, computers and communications	3,4,5,6
E. Battle space expansion	E1 Satellite, fiber, wire, and long-range wireless communications	3,5
	E2 Automated systems	2,7,8,9,10,11,12,13
F. Information protection	F1 Nonjammable communications	3,15,16
	F2 Nonpenetrable databases	2,15
	F3 Unbreakable crypto and other security systems	15
G. Exploit modeling and simulation	G1 Distributed interactive simulations	All
	G2 Support exploration of future requirements	All

[a] There are 17 technologies, represented here by number. The list of 17 appears in Table 4-1.

An alternative approach is to develop a framework for information system development that leverages the commonality across the requirements. This approach, which emphasizes reuse, modularity, flexibility, extensibility, and ease of evolution (Frankel, 1994; Frankel et al., 1995), is central to the discussion of architectures that appears below.

ARCHITECTURE

The commercial sector has recognized the considerable advantages of developing an open architecture based on widely accepted standards and interoperable components as a framework for new system development (Comer, 1991; International Standard ISO 7498, 1990). The commercial marketplace has responded with a set of interoperable hardware and software that facilitates technology insertion and mitigates obsolescence. Legacy systems, even those that are nonstandard, can continue to be used as long as they have standard interfaces.

The advantages of open architecture are recognized in the Technical Reference Model (TRM) of the Department of Defense (DoD) Technical Architecture for Information Management (TAFIM) developed by the Defense

TABLE 4-3 Building Block Technologies and the Associated Army Functional Requirements They Enable

Building Block Technologies		Functional Requirements[a]
1.	Lightweight, rugged, portable appliances and terminals	C2, C3, G1, G2
2.	Storage systems for multimedia information	A6, A8, B1, B2, E2, F2, G1, G2
3.	Communications platforms that support people on the move	A5, A6, B1, B2, B3, B4, C2, C3, C4, D1, E1, F1, G1, G2
4.	Information capture technologies	A1, A2, A3, A4, D1, G1, G2
5.	Protocols and related functionality to support communications	A5, A6, B1, B2, B3, B4, C2, C3, C4, D1, E1, G1, G2
6.	Distributed computing environments and operating systems	A6, B1, B2, C1, C2, C3, D1, G1, G2
7.	Information filtering systems	A6, A8, E2, G1, G2
8.	Multimedia database management systems	A6, B1, B5, E2, G1, G2
9.	User-friendly multimedia user interfaces	A9, B5, E2, G1, G2
10.	Multimedia information analysis and processing building blocks and middleware services	A2, A3, A4, A7, A8, E2, G1, G2
11.	Multimedia information access capabilities	A6, A8, B2, B3, B4, E2, G1, G2
12.	Decision support tools, groupware, multimedia teleconferencing	A7, B4, E2, G1, G2
13.	Multimedia messaging capabilities	B3, E2, G1, G2
14.	Simulation: systems and applications	G1, G2
15.	Security technologies	B2, B3, B4, F1, F2, F3, G1, G2
16.	Network management systems	A5, A6, B2, B3, F1, G1, G2
17.	General purpose languages, tools, development environments	C1, C2, G1, G2

[a] The letter-numeral designations appearing here are drawn from Table 4-2.

Information Systems Agency and applicable to all military services (DISA, 1994). The Army Science Board has recommended a technical architecture for the digital battlefield based on the TRM and also on the same standards-based approach adopted by the commercial sector (Frankel, 1994; Frankel et al., 1995). The Army Science Board approach defines an open architecture in terms of standards, protocols, and definitions, and it provides a means to insert new technology rapidly and to transition away from legacy systems. The Army Science Board approach includes a process and an organizational structure for developing and enforcing the technical architecture.

The philosophy behind the committee's generic multimedia architecture (introduced in Chapter 3) and the Army Science Board recommendations for a technical architecture are similar, with the primary difference being the level of detail. The committee's multimedia architecture was depicted in Figure 3-2.

On March 31, 1995, the Army issued Version 3.1 of its evolving C^4I Technical Architecture (Department of the Army, 1995). This document is part of the ongoing response to the 1994 Army Science Board recommendations. Version 3.1 defines the three-layer Common Operating Environment (COE) shown in Figure 4-1. The COE layers can be correlated with layers of the committee's multimedia architecture as described below.

The top layer of the COE contains "Mission Area Applications" and Support Applications. These correspond approximately to specific applications (Layer V) and the generic applications/enablers (Layer IV) of the committee's multimedia architecture framework. The middle layer of the COE, called the Application Platform Entity, corresponds approximately to the functionality in Layer II and III of the committee's multimedia architecture plus Layer VI (security and network management functions). The bottom layer of the COE, the External Environment Interface, includes, mostly by implication, Layer I of the committee's multimedia architecture.

The committee's multimedia architecture should be viewed as a conceptual (as opposed to detailed) specification of architectural layers and interrelationship of components, fully consistent with the technical architecture currently being created by the Army. When viewed as a conceptual architecture, it becomes apparent that many underlying technologies (Layers I through IV and Layer VI) can and should be shared across the common Army-specific applications that exist at Layer V. Further, as discussed below, building block technologies that may require Army-specific developments appear primarily in the bottom and top layers of the multimedia architecture, while the middle-layer technologies are more generic. This arrangement suggests that, in general, COTS technology should be preferred when implementing the middle layers of future information systems.

APPLICABILITY OF COMMERCIAL TECHNOLOGY TO ARMY NEEDS

In this section, the committee makes recommendations as to whether the Army should adopt commercial technology (C), adapt commercial technology (M), or invest in producing its own technology (A) when drawing upon the building block technologies to meet its functional requirements. Because each building block technology is, in actuality, a collection of closely related enabling technologies, and because COTS technology may satisfy some Army requirements, but not others, the committee recommends a combination of C and M in four cases; a combination of C and A in two cases; and

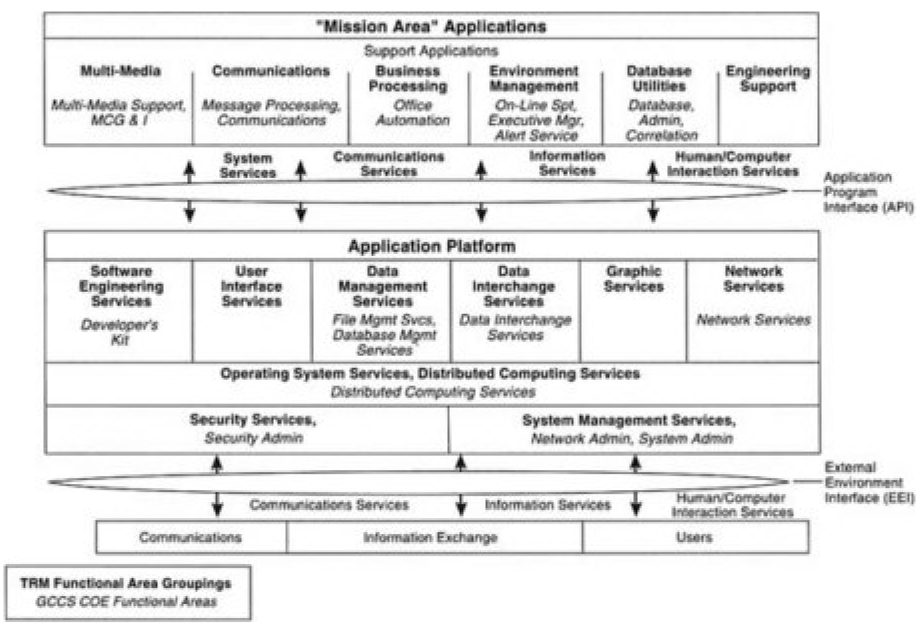

Figure 4-1
Common Operating Environment (COE) Architecture.
Source: Department of the Army, 1995.

a combination of C, M, and A in three cases. The committee recommends C only in the remaining eight cases. As will be discussed below, even where the committee recommends C only, it is recognized that the Army will need to adapt these technologies to take into account Army-specific security needs. Representing security needs in Layer VI of the committee's multimedia architecture as a vertical layer is meant to indicate that security concerns are embedded in all layers of the architecture and should not be used as justification for Army-produced building block technologies where there is a large commercial sector market pull for the development of the same technologies. A more detailed definition of C, M, and A follows.

- The designator C indicates that the commercial market pull is so great that industry will develop these technologies faster than the Army could. More explicitly, the commercial sector is already or will soon be investing tremendous resources to develop the technology. The Army should adopt these technologies off-the-shelf to meet its needs because it will not likely be able to create a competitive advantage for itself by pursuing Army-specific development.
- The designator M indicates that the committee recommends the Army modify or adapt commercial technologies to meet its requirements. Where this is the case, it is advisable that the Army consider its requirements with a view toward commercial product availability. In some instances it will be possible to change the requirement with little or no compromise in functionality, in order to more readily adapt commercial technologies. In other instances, working with industry as a partner or creative first user will foster the smoothest adaptation of commercial products.
- The designator A indicates that the technology is one in which the Army should invest. In this case the committee believes that some of the Army requirements are unique and that industry will not develop this technology on the time scale the Army needs. It is through these investments that the Army can gain a competitive advantage over its adversaries.

A summary of the committee's recommendations is given in Table 4-4. It is interesting to note, with reference to Figure 3-2 and Table 4-4, that the recommended Army investment is heavily focused at the bottom layer and top layer of the architecture and on security technology in Layer VI. For the most part, the middle-layer technologies should be acquired through commercial sources. With respect to security concerns, isolating Army-specific security requirements by using standard interfaces between security functionality and the Layers I–V building blocks will best allow the Army to keep up as commercial building block technologies evolve.

An explanation of the individual recommendations is given throughout the rest of this section. To support these recommendations, it is helpful to refer to the discussion of systems in Chapter 3. As with the discussions of Chapter 3, the recommendations are ordered according to the layers of the committee's generic architecture (Figure 3-2). For example, when the committee looked at the existing and emerging applications of cellular and wireless systems in Chapter 3, it noted that users of these systems require lightweight, easy-to-use appliances with long battery life-times (between charging) and that they expect to be able to move freely while on foot and in vehicles. They also expect their communications to be secure from unauthorized interception and to be reliable in terms of both the integrity of the information communicated and the dependability of the applications they use.

The committee sees a great deal of overlap between these commercial user needs and those of soldiers and commanders in the field. It is recognized that there are also some special requirements on the battlefield, including the need to deploy a supporting infrastructure of cell sites (or functional equivalent) as the battle unfolds and special concerns with respect to low-probability-of-detection of wireless emissions.

When the committee looked at electronic commerce applications in Chapter 3, it saw major concerns by commercial users with regard to security and network integrity to guarantee high availability of applications. These concerns overlap substantially with those of battlefield applications.

The discussions of emerging commercial intelligent transportation systems in Chapter 3 illustrate the similarity of these applications with the Army's needs for situational awareness (discussed in Chapter 2). Both intelligent transportation systems and the battlefield applications involve broadcast information that must be suitably filtered, and in some cases specifically formatted and routed, to meet the needs of multiple recipients. Both involve the achievement of a common view of a complex situation. Both will require that stringent reliability requirements are met.

Finally, the discussions of residential-information-service applications underscored the importance of ease of use in mass market commercial applications. Ease of use is also of critical importance in battlefield applications.

RECOMMENDATIONS (LAYER I—PHYSICAL PLATFORMS)

Building block technologies discussed under Layer I—Physical Platforms of the generic architecture

TABLE 4-4 Recommendations for Commercial, Modified, or Army-Specific Products in Each of the Building Block Technology Areas

Architecture Layer[a]	Building Block Technology	C Commercial	M Modified	A Army-Specific
I	1. Lightweight, rugged, portable appliances and terminals	**X**	X	
I	2. Storage systems for multimedia information	**X**	X	
I	3. Communications platforms that support people on the move	**X**	X	X
I	4. Information capture technologies	**X**	X	X
II	5. Protocols and related functionality to support communications	**X**		
II	6. Distributed computing environments and operating systems	**X**		
III	7. Information filtering systems	**H**		X
III	8. Multimedia database management systems	**X**		
III	9. User-friendly multimedia user interfaces	**X**	X	
III	10. Multimedia information analysis and processing building blocks and middleware services	**X**		
IV	11. Multimedia information access capabilities	**X**		
IV	12. Decision support tools, groupware, multimedia teleconferencing	**X**		
IV	13. Multimedia messaging capabilities	**X**		
V	14. Simulation: systems and applications	**H**	X	X
VI	15. Security technologies	**X**		X
VI	16. Network management systems	**X**	H	
VI	17. General purpose languages, tools, development environments	**X**		

[a] Layers I–VI depicted in Figure 3-2.

(Figure 3-2) include lightweight, rugged, portable appliances and terminals; storage systems for multimedia information; communications platforms that support people on the move; and information capture technologies.

Lightweight, Rugged, Portable Appliances and Terminals

The component hardware technologies underlying portable computing devices (e.g., laptop computers and personal digital assistants) include processors, volatile memory, long-term storage such as disks and flashcard memory, batteries, and displays. As evidenced in Chapter 3, commercial research and development (R&D) has produced remarkable technological advances in all of these areas, with continued advances forecast for the future. Processor speeds are increasing; memory storage densities are increasing; ever-improving (larger, higher brightness, better resolution) display technologies are appearing; lightweight batteries are offering increased energy densities and improved ruggedness. Perhaps most remarkably, these advances are occurring while prices for the new technology continue to fall. Given these positive trends and the expenses involved in developing these technologies and creating manufacturing facilities for them, the Army should leverage commercial efforts in component hardware technology.

For example, whereas the Army and, more generally, the Defense Department have pioneered in such technologies as virtual reality displays and heads-up displays, commercial counterparts that are appearing in the marketplace can be employed in applications such as helmet-mounted displays and components of gunsights. These technologies will also enable an embedded training capability for soldiers that can be utilized in both training and battlefield environments.

There are, however, some areas in which Army-specific requirements may not be met by existing and emerging commercial technology. Improved ruggedness and environmental tolerance of appliances and terminals may be needed to meet Army requirements. Commercial products are built with the bumps, drops, and foul weather encountered by a business person in mind—a significantly more benign environment than would be found on the battlefield. Even when COTS technology can be used, ruggedness concerns may dictate that the Army choose a more expensive COTS technology over another (e.g., flashcard memory for long-term storage rather than disk drives with movable parts). Improved input devices (e.g., a replacement for a mouse or a trackball) may also be needed since these devices will be operated in stressful environments (e.g., in a moving tank or by a soldier in motion). Battlefield environments may expose physical equipment to nuclear radiation and to electromagnetic pulse (EMP) effects resulting from the high altitude detonation of a nuclear device. There may also be Army-specific requirements for low probability of intercept (LPI) and low probability of detection (LPD), that is, for limiting or controlling electromagnetic radiation from physical equipment that might be received and utilized by eavesdroppers or might disclose the presence and location of the equipment. All of these requirements may necessitate customized physical enclosures into which COTS physical computing technologies are incorporated. In extreme cases these requirements may necessitate the selection of one COTS technology over another (e.g., some COTS technology may be more susceptible to EMP or may radiate more detectable radiation than another, above and beyond what can be compensated by physical enclosure design). Finally, any data stored in a computing device may be subject to capture and hence should be appropriately protected.

Recommendation: C, M

Storage Systems for Multimedia Information

There is a large perceived commercial market for multimedia applications. Gaps between the needs of these multimedia applications and the capabilities of commercial storage systems are being filled by a large commercial R&D effort. Although Army investment in research on promising new storage technologies (e.g., multilayer optical disks) may be appropriate, it is unlikely that Army-specific development of storage systems could close gaps between Army needs and commercial capabilities any faster than commercial R&D activities will close those gaps. The Army should adopt commercial multimedia storage and server technology, using customized packaging (when required) to meet unique Army requirements with respect to shock and vibration resistance, ruggedness in general, low emissions of radiation to protect against intercept and detection, and nuclear radiation and EMP resistance. In addition, some physical packaging and other modifications may be required to protect stored information in the event of capture of a storage system.

Recommendation: C, M

Communications Platforms that Support People on the Move

The commercial platforms described in Chapter 3 to support mobility do not, in general, meet traditional military specifications for anti-jam, LPI, LPD, nuclear radiation and EMP resistance, and rapid deployment in battlefield environments. Nonetheless, several of the emerging commercial low-earth-orbit satellite systems should be of interest to the Army because they are (a) truly global-coverage systems; (b) targeted for small, inexpensive information appliances that could be used by individual soldiers and on small vehicles; and (c) all-digital systems to which military-grade encryption subsystems could easily be added. These systems may be useful to the Army for maneuvers, rescue, day-to-day operations, such as a backup in wartime applications. The Army should study the capabilities and limitations of these systems and consider adding desirable Army-specific modifications to planned commercial terminal equipment. Since these systems have multinational partners, the Army should expect that it may be politically difficult to add Army-specific "hooks" into system infrastructures.

For local, mobile communications, the Army should approach commercial vendors of cellular, cordless, and personal communication systems to add unique Army needs to those already being considered for commercial markets. In particular, some components (e.g., handsets, subsystems) of the low-cost commercial systems being considered for rapid deployment in developing countries may be adaptable to Army needs, particularly if unique Army requirements are incorporated into their designs. Requirements for rapidly deployable and survivable cell sites (or functional equivalents in such forms as unmanned aerial vehicles) to serve battlefield environments are far less likely to be met by commercial products. It is here that the Army should develop Army-specific technology for its competitive advantage.

As discussed in Chapter 3, in addition to providing links from wireless nodes to end users, a communications platform to support soldiers on the move must include backbone and feeder transmission and switching facilities to connect cell sites or their equivalent. In the commercial arena, these facilities often consist of fixed fiber optic, copper cable-based, and microwave facilities. The microwave facilities may be deployed on highly stable towers or buildings. In the battlefield, physical cables can be used in some situations, but often wireless facilities will be required to implement backbone and feeder links. In the battlefield, towers that support antennas may be relatively unstable, and LPI considerations may lead to the need for special adaptive antennas to project signals properly. As discussed in Chapter 3, standards are emerging in the commercial arena to support the transport of asynchronous transfer mode (ATM) signals over error-prone environments, and thus the use of battlefield wireless systems to carry ATM will likely be enabled by these COTS standards.

Information Capture Technologies

As with many of the building block technologies, much of the Army's gain comes from exploiting those technologies in its systems in which the commercial world has taken a lead. For example, the dramatic advances in video and image camera technologies (e.g., camcorders and cameras associated with multimedia personal computer applications) discussed in Chapter 3, as well as the associated technologies for digitally encoding and processing image and video information, represent COTS technologies that should be applied to Army battlefield applications with only minor modifications to address such issues as ruggedness.

There are, however, image and video capture technologies in which the Army has traditionally been far ahead of commercial applications and which have produced key differentiating advantages for the Army over its adversaries, particularly in the area of low-light image intensifying sensors and infrared sensors.

Some infrared sensors have found widespread commercial use, such as the infrared motion detectors used in motion detector lighting systems and burglar detection systems. These systems differ from those required for Army use. Army systems must be more sensitive than justified by economic considerations for consumer devices, as the opponent must be presumed to be actively engaged in concealment. Army sensor systems may be chosen to operate in a purely passive mode, rather than emitting energy in a feedback mode, to preserve operator stealth. Finally, Army sensor systems must be presumed to operate in far harsher environments than consumer technologies.

Many of these goals can be achieved with modifications of commercial products, such as infrared motion detectors. Telerobotic sensors, some with commercial analogs, will play a key role in enabling and facilitating remote operations, reconnaissance, and intelligence-gathering on future Army battlefields. Systems with no commercial analog may be Army-specific. Examples include infrared binoculars and low-light amplification gun sights. Very specialized examples include active antennas in the electromagnetic spectrum, such as synthetic aperture radar (SAR).

Commercial technology plays a role in the signal processing tasks associated with many advanced sensors. In particular, advanced digital signal processing technologies can aid in separating useful information from chaff across the electromagnetic spectrum. The wide use of these chips in consumer multimedia applications has resulted in rapidly improving price and performance, but the same technology can be, and is being, used in signal recovery in a military environment. Army use of information capture technologies also tends to be more sophisticated than consumer use since the goal is gathering location, size, movement rate, and other pertinent data about an opponent taking active steps to conceal these characteristics (e.g., by moving at night, in the rain, under cloud cover, in radio silence, or using other forms of sensory camouflage). Sensory data in this setting must be combined for decision-making purposes, meaning that the sensors must be integrated with other information collection and distribution mechanisms, such as the Army's communications networks.

An important sensor capability that is now widely used commercially, although it emerged from DoD requirements, is the Global Positioning System (GPS). A constellation of satellites generates signals which allow receivers on the ground to determine their longitude, latitude, and elevation. The accuracy with which this determination can be made depends upon whether the signals transmitted by the satellites have been intentionally degraded by varying their underlying timing precision and by broadcasting incorrect orbital position information. This "selective availability" degradation is used to deny military adversaries the higher accuracy that can be obtained by receivers capable of receiving an encrypted signal that bypasses the degradation.

With selective availability activated to the extent typically employed today, commercial GPS receivers can achieve an accuracy of 100 meters horizontally and 156 meters vertically with 95 percent probability. If selective availability is not activated, GPS receivers can achieve an accuracy of 20 meters horizontally and 30 meters vertically.

In addition, the use of a method called differential GPS—which depends on correction signals that are broadcast from locations which are in positions known to a high degree of accuracy—can allow receivers to determine their locations to accuracies of less than a meter. GPS receiver technology is being employed in consumer devices costing several hundred dollars, with costs declining along the usual trend curves associated with electronics technologies. These commercial GPS technologies and products can be employed in Army battlefields.

Recommendation: C, M, A

RECOMMENDATIONS (LAYER II—SYSTEM SOFTWARE)

Building block technologies discussed under Layer II—System Software of the generic architecture (Figure 3-2), include (a) protocols and related functionality to support communications, and (b) distributed computing environments and operating systems.

Protocols and Related Functionality to Support Communications

With millions of computers worldwide running Internet protocols, there is a large base of installed machines and commercial enterprises to support and develop technology based on Internet standards. Internet protocols are being extended to support real-time multimedia applications. Importantly, Internet protocols were designed with military applications in mind; several Internet protocols have status as military standards. The Internet standards body, the Internet Engineering Task Force, has an ongoing effort to develop protocols to support communication in a mobile environment—an effort that should be of considerable interest to the Army. Since the Internet standardization process is an open one, the Army should participate in this process to ensure that emerging and planned Internet standards adequately address Army needs.

The asynchronous transfer mode (ATM) protocols are still in the process of being "fleshed out" but are anticipated to be of considerable importance in the future. The committee notes that there are several ATM test beds within the DoD. A rapid standardization process is being pursued by the ATM Forum. The Army can play an important role as an active participant in the ATM Forum and other ATM standards development activities. In particular, wireless ATM has received little attention in the Forum to date, and the Army's needs would be an excellent driver for wireless ATM.

Given the documented success and scope of the Internet, the widespread industry support for ATM, and the level of commercial effort being expended to expand the capabilities of both, it is unlikely that defining and developing a new or proprietary Army-specific communications protocol suite could provide the Army a competitive advantage, as opposed to adopting and adapting COTS technology.

Recommendation: C

Distributed Computing Environments and Operating Systems

The DoD's need for better-integrated information sharing within and between the Armed Forces can be well served by commercial distributed computing technologies and operating systems. Rather than developing new operating systems or environments, the Army should adapt the commercial technologies by adding multilevel security, special character sets for multinational language support, and other unique capabilities.

The effective use of distributed computing environments and operating systems is closely tied to the need for an Army "enterprise-wide," logical information-sharing architecture. Army efforts to create a technical architecture, which were discussed earlier, represent an excellent start. Two challenges accompany using such a model. First, the model is inherently computing-centric. While this is appropriate for sharing text, images, and other forms of data, the use of the model for voice communications is not so clear. A fully integrated multimedia information system requires that voice not be handled separately. Second, full implementation of the model will go beyond what can reasonably be included in hand-held or other small information appliances. The details of the architecture must be designed so as to allow small-scale implementations of portions of the architecture.

Recommendation: C

RECOMMENDATIONS (LAYER III—MIDDLEWARE)

Building block technologies discussed under Layer III—Middleware of the generic architecture (Figure 3-2) include information filtering systems; multimedia database management systems; user-friendly multimedia user interfaces (e.g., speech, graphical user interfaces); and multimedia information analysis and processing building blocks and middleware services.

Information Filtering Systems

Because information filtering capabilities are critical to the success of the commercial applications envisioned for an emerging advanced national information infrastructure, there are large commercial R&D efforts under way to develop new and better approaches for indexing and storing information in electronically accessible form, searching through heterogeneous distributed databases, and filtering arriving information according to user needs and preferences. Much of this existing and emerging technology should be directly applicable to Army needs and should be used off-the-shelf. There may be some modifications required to handle multilevel security concerns. However, the Army should (a) endeavor to influence commercial technology to put in the "hooks" required to meet the Army's security needs, or (b) adapt its own requirements to be compatible with commercial security capabilities, rather than attempting to develop Army-specific information filtering systems, which have counterparts in the commercial domain.

The committee recognizes the fact that the Army has traditionally been at the forefront in technologies that enable machine interpretation of images and specialized types of data fusion. In these areas, Army-specific R&D can lead to unique, competitive capabilities. Finally, the Army should continue to fund promising research in information filtering to accelerate the emergence of commercial capabilities that meet Army needs.

Recommendation: C, A

Multimedia Database Management Systems

For commerce, advertising, education, and entertainment, the commercial potential for multimedia database management systems is overwhelming. In most cases, commercial R&D in this area will progress much more quickly than it would with Army-specific development programs. For its needs, the Army should experiment with emerging multimedia database technologies as any large commercial customer would. Some examples of large-scale, ongoing trials using multimedia databases include the Library of Congress and digital library efforts noted earlier in Chapter 3. One Army-specific concern in multimedia database technology not addressed in these ongoing efforts is the issue of data security and authenticated user access.

Recommendation: C

User-Friendly Multimedia User Interfaces

Administrative and logistical functions in the military could adopt speech recognition on standard desktop systems having suitable processor performance and necessary sound-card functionality. Applications would fall into the same categories in use in the commercial sector (e.g., speech-enabled forms processing) as well as non-frontline military applications such as supply and equipment maintenance. Combining COTS speech recognition capabilities with mobility through the use of COTS portable computing systems could be of significant value in rear-area activities. However, the effect of background environmental noise in some of these applications on the accuracy of current speech recognition systems needs to be quantified.

The value of current speech recognition systems in combat environments is doubtful. In such life-and-death situations, accuracy and response time are critical. Today's systems are not accurate and responsive enough in such environments. Nevertheless, significant progress in voice recognition technologies may result in advances that overcome the limitations of these technologies in combat environments. Such breakthrough advances are difficult to predict, and the Army should continue to closely monitor progress in the field of speech recognition, both at universities and at industrial laboratories, in order to detect breakthrough advances as they emerge in their earliest stages and prepare to be an early adopter of such advances in battlefield applications.

Because of the large and growing commercial R&D investments in improving speech recognition accuracy to meet the needs of commercial applications, it is unlikely that Army-specific speech recognition technology developments could produce a competitive advantage for the Army. The base technologies for speech recognition are available immediately on the commercial market or will be maturing into the mainstream within the next few years. Expenditures by the military should be leveraged off these COTS technologies, with little modification or customization for systems used in the administrative applications.

For its high-noise applications like equipment maintenance, the Army should leverage the rapidly moving commercial market, which is currently pursuing speech recognition in adverse environments (e.g., heavy equipment operator on a factory floor). The Army should also stay abreast of the commercial advancements for possible future opportunities to use speech recognition in more robust ways.

As with speech input and recognition technology, multimedia presentation (e.g., graphical user interfaces (GUIs)) and COTS input technologies (e.g., mouse and pen-based devices) would be applicable in Army rear-area activities. These technologies would also be appropriate in other nonstressed Army environments where the worker-at-a-desk model for which these technologies were developed is applicable.

In combat environments, however, there are additional considerations that may require that the Army adapt COTS multimedia user interface technology. For example, the weight and ruggedness of input devices will be Army concerns. In a stressful battle scenario, a soldier may have limited ability to view or choose among information, making the multiwindowed, multi-icon GUI typically found in COTS desktop or laptop multimedia computers inappropriate. Also, the soldier on the move (whether on foot or in a vehicle) may have difficulties with desk-based pointing devices, such as a mouse, trackball, or other device requiring fine motor control. This concern was noted by Army personnel during the committee's visit to Fort Gordon.

Although the committee believes that the Army should adopt and adapt COTS user interface technology, one important area that should receive further attention is research on human perception and performance in highly complex, temporally sensitive, information rich environments representative of battlefield situations. A vast amount of scientific data has been collected and is being collected (e.g., in the commercial deployment of residential information services, as discussed in Chapter 3) that will impact both commercial (entertainment and industrial) and military applications. Work in these areas includes visual, auditory, and other sensory acquisition of information. This type of work is particularly pertinent to (a) enabling commanders to convey their intentions and distribute information in the most effective manner, and (b) enabling subordinate commanders and individual soldiers to receive the information and understand the commander's intentions.

Recommendation: C, M

Multimedia Information Analysis and Processing Building Blocks and Middleware Services

Because of the importance of multimedia information analysis and processing building blocks and middleware services in commercial multimedia applications, as well as the large size of the commercial multimedia application marketplace, commercial R&D efforts to advance these technologies will be great and driven by many firms. The committee believes that gaps between commercial technology capabilities and unmet commercial and Army needs will be closed much more quickly by commercial R&D activities than they would be by Army-specific R&D.

The Army may find it advantageous to participate in commercial activities to influence these trends in ways that support Army-specific requirements and to fund promising research efforts that can produce new dual-use technologies. There may be some special middleware building blocks that are needed for Army applications and have no commercial counterparts. These would require Army-specific development.

Recommendation: C

RECOMMENDATIONS (LAYER IV—GENERIC APPLICATIONS/ENABLERS)

Building block technologies discussed under Layer IV—Generic Applications/Enablers of the generic architecture (Figure 3-2) include multimedia information access capabilities; decision support tools, groupware, multimedia teleconferencing; and multimedia messaging capabilities.

Multimedia Information Access Capabilities

With the remarkable growth of the World Wide Web last year, 1994 will likely be marked as the year that networked-multimedia-information access (particularly, access and display of stored, combined text and images) became a reality. Commercial ventures in this area are just beginning to appear with products such as enhanced, networked multimedia viewers (e.g., Mosaic, Netscape ®). World Wide Web growth, the quick startup of commercial ventures, and the level of interest in both the technical and popular press indicate future significant commercial interest in this area. Research efforts in multimedia information access are also ongoing in numerous industrial, government, and university research labs.

Regardless of whether the World Wide Web and its protocol become the future standards, it is almost certain that the underlying multimedia data will be represented in the standard formats discussed in Chapter 3. It is crucial that the Army maintain its data in such formats (or be able to convert data to and from such formats) if it expects to leverage fully commercial efforts in the area of multimedia information access.

Recommendation: C

Decision Support Tools, Groupware, Multimedia Teleconferencing

As evidenced in our discussion of the decision support technology in Chapter 3, many commercial products have been announced that support collaborative, group-oriented communication and information sharing. Unfortunately, products from one company will likely not interoperate with those from another company. This reflects the lack of accepted standards in the area and a technology that is not yet fully mature. Nonetheless, the need to interoperate is a compelling one, and open standards will emerge over time. The significant number of currently available commercial products, combined with ongoing research efforts in industrial, government, and university research laboratories, indicates that this is an area in which the Army will be able to significantly leverage commercial technology. Once again, security considerations are one area where industrial efforts may fail to meet Army-specific needs.

Recommendation: C

Multimedia Messaging Capabilities

The need to transmit, store, and display multimedia messages will be a common requirement of all future networked systems, whether commercial or military. The already pervasive use of text-based electronic mail today will evolve into the multimedia electronic mail of tomorrow as network users continue to acquire multimedia-capable computers.

Standards for multimedia mail have already been defined both for the Internet and Open Systems Interconnection (OSI). Given the large installed base of Internet and OSI-compliant protocols, it is likely that future commercial multimedia mail systems will conform to these standards. If multiple standards exist, it is likely that mail programs will be able to convert between standard formats, since interoperability is of critical importance.

Recommendation: C

RECOMMENDATION (LAYER V—SPECIFIC APPLICATIONS)

General Observations

This section addresses Layer V of the generic architecture of Figure 3-2. As discussed in Chapter 3, the factors that determine whether an application should be developed on a customized basis or be adopted or adapted from off-the-shelf software are the perceived uniqueness of the needs that the application must meet, whether or not the organization or individual who will use the application aspires to obtain a competitive advantage by optimizing the application to meet its needs, and whether or not the organization or individual has a realistic expectation of being able to produce a customized application that will be better than what it can purchase off-the-shelf in the time frame that customized application would be available and used.

For example, it seems self-evident that the Army would develop customized application software to manage target acquisition, tracking, and associated weapons assignment and fire control. This is a collection of related applications with which the Army would seek to obtain a competitive advantage over its adversaries, and where it is not likely that analogous commercial applications, to the extent they exist, would cause the creation of COTS application software that is better than what the Army could produce on a customized basis. However, as stressed throughout this report, the Army should utilize COTS building block technologies to the maximum extent possible in creating such applications in order to leverage the rapid pace of technological improvements that these building blocks enjoy; and the Army should create such applications in the context of an overall technical architecture to achieve the benefits of building block reuse, interoperability, and the ability to insert new technologies, as discussed earlier and in Chapter 6 of this report. It is far less clear that the Army would need to create customized word processing or spreadsheet applications rather than use those that are available off-the-shelf commercially.

Thus, the committee will make no general recommendations regarding whether the Army should adopt or adapt COTS application-level software or whether it should develop Army- specific application-level software, other than to urge the Army to adapt or adopt COTS software whenever its needs are not unique and it does not expect to gain a significant competitive advantage from that application software. Also, the committee urges the Army to utilize COTS building blocks in the context of a technical architecture when creating customized applications.

The committee has focused specifically on simulation systems and simulation applications because of the emphasis that has been placed on simulation by the representatives of the Army who met with the committee. The committee's recommendations with respect to simulation systems and applications follow below.

Simulation: Systems and Applications

Commercial simulation software is moving toward more integrated support of the modeling and simulation enterprise, including support of software development, database management, model specification, model-to-architecture mapping, and multiple resolution levels. Such methodological tools are necessary for the development of the large virtual and live simulations of major interest to the Army. Commercial simulation software that supports visualization, such as computer-aided design and manufacturing software, should have application to battlefield visualization of complex two-and three-dimensional objects, including the battlefield itself. Commercial simulation software used in medical imaging applications has already been shown to have application to telemedicine on the battlefield.

Therefore, the Army should employ COTS developments along these lines where they exist and encourage their development where they do not. For example, through the "federated" laboratory concept,[1] the Army could solicit work toward the objective of integrating commercial (or commercializable) simulation environments into the design and management of distributed simulations. The actual implementation of distributed interactive simulation for virtual and live training applications is very much Army-specific and will not be developed commercially on any significant scale without Army participation.

Recommendation: C, M, A

RECOMMENDATIONS (LAYER VI—MANAGEMENT/SECURITY)

Building block technologies discussed under Layer VI—Management/Security of the generic architecture (Figure 3-2) include security technologies; network management systems; and general purpose languages, tools, and development environments.

Security Technologies

As discussed in Chapter 3, there are increasing concerns regarding the security of commercial networks in terms of their vulnerability to eavesdropping, protection of information from unauthorized access, vulnerability of networks and servers to major outages caused by accidents, denial-of-service attacks, and other problems. These concerns will grow as the vision of a national information infrastructure emerges in the form of increased usage of networks to conduct all aspects of commerce, health care, government services, personal business, and other civilian activities.

On this basis, one could argue that commercial applications will produce a very large market pull leading to the creation of effective security technologies that can readily be adopted and adapted to meet Army needs. Commercial technology in the area of security is evolving rapidly, particularly in areas related to electronic commerce such as digital signatures, digital time stamps, and electronic cash. The desire for privacy has been strong enough that credible systems (such as the "Pretty Good Privacy" system) are in widespread use on the Internet worldwide. Freely available Digital Encryption Standard (DES) software can operate at or near Ethernet LAN speeds.

On the other hand, defense and intelligence applications have traditionally been the driving force behind the creation of many of the most advanced and the most powerful security technologies, some of which have subsequently been adapted for commercial use. The DoD, Advanced Research Projects Agency (ARPA), and the National Security Agency are currently playing a key role in helping to promote the creation and proper use of security technologies in commercial applications. On this basis, one could argue for a continuing strong role of the Army, DoD in general, and the intelligence community

[1] A concept for extending the capabilities of the Army Research Laboratory by using civilian laboratory resources.

in the creation of security technologies that produce a competitive advantage over adversaries.

As mentioned earlier in this report, it is well to view security as a journey rather than a destination. New and more sophisticated threats continually emerge, based on the availability of more sophisticated computing technologies, more efficient algorithms, and other advances by talented hackers, criminals, and terrorists. This suggests that true security in the Army sense will always involve more than can be provided by routine application of off-the-shelf technologies.

Thus, it is not clear at this time whether the Army and DoD in general will continue to lead in the creation of the most powerful security technologies, whether they will transition toward the use of COTS for essentially all of their applications, or whether they will pursue some combination of these.

The committee believes it is likely that at least some large classes of Army security applications can be satisfied by COTS security technologies, even if there remains a significant residual set of applications that must be served by Army-specific developments. It should be pointed out that the committee did not have access to classified information that might allow a more thorough assessment regarding the extent to which COTS technology could be applied to the broad range of Army security applications.

With all of the above as background, the committee decided to make the recommendation that the Army adopt and adapt as much emerging COTS security technology as possible, while still engaging in Army-specific development of those security technologies needed to meet truly unique Army requirements. The Army, and the DoD as a whole, can stimulate the development and accelerate the use of robust security protocols built on publicly available technologies. This approach has the advantage that these protocols will then be embedded in next-generation COTS that the Army can purchase and embed in its systems. Examples of this process include ARPA's stimulation of better network and protocol security mechanisms in the next generation Internet Protocols and the desirable participation of the Army or DoD in evolving a secure Hypertext Transfer Protocol (HTTP). This process should continue as threat models change over time.

Even with all of the caveats and ambiguities described above, the committee expects that the percentage of Army security applications that can be satisfied with emerging COTS security technologies will be substantially larger in the future than in the past.

In addition to issues related to algorithms, key management, and system administration to ensure that security requirements are met, the Army may have requirements with respect to electromagnetic emissions (LPI and LPD) and with respect to nuclear radiation and EMP effects (various denial-of-service threats including loss or destruction of data) that are more stringent or more compelling that those associated with most commercial applications. This was discussed earlier in this chapter under the heading Layer I—Physical Platforms, where the need for Army-specific physical packaging and the careful selection among alternative COTS technologies was pointed out. Finally, the Army, and DoD in general, may have requirements for bulk encryption of very high speed data signals (i.e., encryption of the entire multiplexed signal, rather than its lower speed tributary signals) which cannot be met by using general purpose microprocessors to execute encryption algorithms expressed in software. This may lead to the requirement for Army-specific hardware modules, which can be add-ons or appliques to COTS equipment which implement very high speed encryption algorithms using custom hardware-based methods.

Recommendation C, A

Network Management Systems

Because of the importance of network management in commercial applications and the large R&D efforts under way to create network management products for commercial information networks, the Army should adopt commercial network management technologies and systems off-the-shelf for its network management applications. There will probably be some Army-specific modifications required to deal with specific security requirements and concerns regarding multiple, simultaneous failures of network elements. However, many of these concerns also exist in commercial applications involving commerce, health care, air traffic control, and so on.

The committee recognizes that, when given a more detailed analysis of Army requirements, the Army may conclude that battlefield conditions are so stressful with respect to failures of systems and subsystems, movement of systems and subsystems, and recovery requirements that commercial network management technologies, even in modified form, cannot meet all of the Army's battlefield requirements. In that case, Army- specific development will be required. However, the committee recommends that the Army start out with the mind set that it will adopt and adapt commercial network management technologies, and that it consider Army-specific developments as a fallback strategy to be avoided if at all possible.

Recommendation: C, M

General Purpose Languages, Tools, Development Environments

The development of a general purpose computer programming language and its acceptance within the software development community (as evidenced by its use by software developers) is an extremely lengthy process. Ada is a case in point. Even after the issuance of an Ada standard and almost two decades after the Ada effort was first conceived, there exist very few unqualified Ada success stories. More recently, the situation has improved as indicated by success stories (many in commercial applications) reported by the Ada Joint Program Office. It is important to note, however, that whatever success the language has achieved has come 20 years after its inception and has had the strength of the Ada mandate behind it.

Because there are several existing general-purpose computer programming languages (such as Ada and C++) that were designed to meet the needs of reliable, real-time systems and embody the principles of modern software engineering, there would appear to be little reason for the Army to pursue anything but pure COTS technology in the general-purpose computer programming language area. Even if deficiencies in existing languages are uncovered, the time frame for developing an accepted language is too large. A more fruitful path would be to influence and extend existing languages through the standards process.

Recommendation: C

AN OPERATIONAL EXAMPLE

Having presented the above recommendations, the committee now moves to an example of how multimedia information technologies could be used by the Army for battle command in the future.

Battle Command in the Twenty-First Century

In Chapter 2, the committee discussed the Army's operational needs to achieve battlefield success in the information age. These needs were described in terms of functional requirements from the user's perspective. Chapter 2 also indicated that the Army recognizes the potential military advantages that can be gained by leveraging the power of information distribution technology. To realize these advantages, Army leaders have initiated a series of battle laboratory experiments, analyses, and field trials aimed at finding optimal approaches to digitize the battlefield. The Army's strategy for change, described variously within the context of "Force XXI," the "Enterprise Strategy," "Joint Venture," and the "Louisiana Maneuvers," also recognizes that the application of multimedia information distribution technologies will lead to fundamental changes in organization, doctrine, training, and all the activities associated with how the Army prepares for and executes combat operations (Army Director, Louisiana Maneuvers Task Force, 1995 and Department of the Army, 1993).

While all the ramifications of how military organizations and warfare could change in the next century may not be clear, the goal of applying the technologies through digitization of the battlefield is to achieve overwhelming battlefield success rapidly and with few casualties. The expectation is that advanced automation and multimedia technologies will lead to a dramatic reduction in uncertainty, significant improvements in shared knowledge, and the practical elimination of misunderstanding between and among all the involved commanders and cooperating organizations on the battlefield. When a commander knows with certainty where all his units are (and their status) and knows with equal certainty the location and status of the enemy; when that information is shared by all subordinate, adjacent, and senior commanders, regardless of their location; when battlefield information and its meaning can be rapidly disseminated to all who need it; and when all of this can be done unambiguously in real time and in a format useful to each commander, the result is a dramatic improvement in battlefield performance and the ability of the commander to control the pace and tempo of the battle.[2] These capabilities define operationally what improved situational awareness and a common picture of the battlefield mean to a commander in battle. They constitute the essential underpinnings for success throughout an expanded, fast-paced, mobile battlefield.

Although it is not the committee's intent in this chapter to predict new tactics or how commanders may execute future battle command, it is clear to the committee that the application by the Army of the information technologies available now or by the turn of the century can have far-reaching effects. If information is shared more quickly and if it is more accurate and timely, it should permit commanders to extend their span of effective control. Organizations may be flatter, with smaller support staffs and fewer levels of command. Actions can be coordinated over wider areas and synchronized more precisely, which may permit innovative tactics for concentrating combat power with fewer forces because of the more

[2] Of course, it is equally important that a commander know with certainty that his battlefield information is not available to the enemy and that the enemy has neither destroyed nor modified it.

efficient use of that power and the confidence that it is being applied effectively.

Army Commanders, the Battlefield, and Multimedia Technology

The committee recognizes that the Army has extensive plans for the operational evaluation of the application of information technologies as part of its efforts to digitize the battlefield. While doctrinal and organizational decisions will evolve from these evaluations, it is useful at this point to describe how commanders in a particular combat operation might use the technologies identified in Chapter 3 to meet the functional requirements outlined in Chapter 2.

The committee's description takes the form of the hypothetical scenario at some point early in the next century. In that scenario, it is postulated that an Army corps is deployed to a theater of war as part of a joint command that will conduct combat operations against an armed enemy. The scenario follows.

* * * * * *

As the Corps commander begins to plan for offensive operations, his focus is on securely gathering information about the enemy and the environment within the area of operations while ensuring that the units within the Corps are prepared, trained, and supported. Explicit requirements for the commander are to preauthorize who may share the information and to have an effective cryptographic key management scheme.

The initial warning order to subordinate commands is initiated over a protected broadcast network. Shortly thereafter, the Corps commander briefs and leads a discussion of the upcoming operation with all the involved commanders via video teleconferencing. Subordinate commanders participate from their own command posts with the necessary staff present to listen, understand, and take part in the discussion. Images of the objective areas and routes of advance are called up from stored files or in real time from satellites, aircraft, or ground sensors for all to view simultaneously. The map images at each command post are identical, and the Corps commander is able to explain his intent, point out specific items of importance, and sketch pictorially the options being considered. This process uses encrypted data transfer over low-probability-of-intercept, anti-jam communications.

At the conclusion of the initial briefing and warning order, intelligence collection systems begin to focus on the most likely courses of action. Support organizations conduct electronic queries of the participating units to determine personnel and logistical status and to assess available materiel stocks. Automated processes determine requirements in accordance with the commander's announced priorities. Necessary replacements, equipment, and supplies are delivered to the appropriate units or identified for later delivery based on predicted consumption and battle intensity.

The Corps commander runs a quick check of unit status. Applying established criteria and standards, the commander is alerted automatically to any unit whose status has fallen below the predetermined standards. These may be adjusted once the battle begins. The Corps staff reviews uncompromised, accurate data on enemy units within the area of operations, directs additional collection efforts, and employs automated processes to analyze terrain, estimate time and distance implications, compute probable consumption rates, and compare alternatives. Computers conduct the repetitive, computational tasks, store information for rapid retrieval, provide prompts and alerts based on preset criteria, and continuously update the databases, maps, and individual status displays. Use of the computers leaves the staff and commanders free to think, consider options, and apply the human perspective to preparing for the operation. Employing an interactive simulation, the staffs rapidly compare courses of action, modify conditions and assumptions, and complete their assessments.

The Corps commander calls up a satellite image of the objective area, then follows in real time an unmanned aerial vehicle as it takes still or video images over the objective area, the approaches to it, and enemy units that could affect the operation. The commander conducts a personal reconnaissance of as much of the area as feasible, but he remains in contact with his own headquarters and subordinate commanders as the plan is developed.

Once the commander selects a course of action, the staff completes the plan. Secured information is shared electronically and through voice communications with the staffs of all the organizations involved in the operation to permit simultaneous parallel planning. When complete, the briefing and discussions once again are via video teleconference. Detailed questions are answered and precise coordination effected so that all clearly understand the intent and concept of the operation. The Corps commander employs a simulation at this point (or possibly later) to review the plan, actions at critical phases, and contingencies to meet unexpected enemy action or potential opportunities.

At lower levels, commanders and their staffs are involved in similar activities. Intelligence information is received continuously from theater and Corps assets as well as those controlled by subordinate commanders.

Preset filters determine the information to be received and stored in the local unit database and the security level to be assigned to the information. The filters are determined by geographic boundaries, types of enemy units, enemy activity, or time frame. Each commander sets specific filter requirements and also establishes criteria for special alerts or prompts.

Throughout the planning process, information is shared between supporting Air Force and Navy units, as well as adjacent Army and Marine Corps maneuver headquarters. Standards, protocols, and operating environments common to all services permit the automated retrieval of relevant information from the databases of all the organizations involved in the operation, regardless of service, and prevent unauthorized modification to the data. Other protections involving user codes, bulk encryption, and physical and electronic hardening prevent penetration or destruction of the shared databases by the enemy.

The lead combat maneuver formations involved in the initial penetration of enemy defenses conduct extensive reconnaissance and training for the operation. Overhead photography and imaging, scout helicopters, foot patrols, and implanted sensors collect information on specific weapons and positions. Commanders at these levels establish precise criteria for alerts concerning the positions of single weapons, the possible construction of new obstacles, and indications of the movement of tactical reserves. They are assisted in the determination of the precise locations of equipment and soldiers by location reports enabled by the GPS.

Shortly before execution of the attack, the penetration force conducts a rehearsal supported by a simulation that feeds enemy activity into the intelligence system. The units and soldiers involved participate with their actual weapons and equipment. Data ports on the armored vehicles and electronic imaging systems transform them into simulators operating in a virtual reality, as seen on their thermal imaging devices, vision blocks, and sights. Follow-on units rehearse similarly, with unexpected situations introduced to force commanders at the lowest levels to execute immediate action drills and contingency plans.

On the evening prior to the attack, patrols infiltrate to positions where they can observe the area selected for the penetration. The joint surveillance and target attack radar system (JSTARS) maintains deep surveillance, watching for the movement of operational reserves. Unmanned aerial vehicles and scout helicopters confirm the locations of tactical reserves and artillery. After arriving in position, one of the patrols detects the movement of tanks into forward defensive positions. Using thermal viewers and miniature cameras, the patrol takes several pictures and contacts the lead unit commander. The images are transmitted securely with precise time and location tags. The commander (a) directs the fire support officer to coordinate artillery and attack helicopter fires to commence 30 minutes prior to the attack, and (b) forwards the images to his commander. This transmission automatically triggers transmission to the adjacent commanders, senior commanders, and the Corps commander, all of whom have preset automatic alerts for information of tank movements in the area of the penetration.

The attack begins with artillery fire on known enemy positions and the precision attack of selected targets. The attack helicopters make contact with the patrol leader, who employs his laser designator on each of the tanks and hands off the targets to the engaging helicopters.

The lead combat elements launch a violent attack. Dismounted soldiers and engineer vehicles clear the mines and obstacles, overwatched by supporting tanks and fighting vehicles. Artillery fire is called for and adjusted by forward observers with automated handoff of targets to the fire direction centers. The location of each tank and combat vehicle and the dismounted elements attacking the enemy position are displayed in each vehicle and on displays at the controlling headquarters, fire support units, and fire direction centers. This information is protected against enemy access. Automated combat identification codes distinguish between friendly and enemy combat vehicles and heavy weapons. Identified targets that cannot be engaged by one tank are handed off automatically to another tank or supporting weapon. Commanders operating from mobile armored vehicles or helicopters follow the battle by listening on the command nets of subordinate and adjacent units and through visual observation. Their display screens provide rolled-up information on the center of mass location of units and their status.

After clearing the position, follow-on forces begin to roll through. The senior commanders request the status of the lead units with automated queries to respective databases; the responses are transparent to the subordinate commanders. Logistical units conduct similar queries on ammunition and fuel status that has been rolled up from the sensors on each combat vehicle in the lead units. Resupply and medical support begin to move forward before the units sense the need and without a request on their part. At this point, the Corps or other senior commanders adjust the plan slightly, based on unit locations and status and the success achieved. The changes in objectives, routes, and missions are encrypted and sent to all commanders involved. Control measures are depicted on all map displays automatically. Alerts the provided electronically and over a protected broadcast network. If necessary, the commander describes his intent graphically in real time to ensure full understanding.

As the attack picks up speed and more units move through the penetration, traffic jams are avoided by constant updates to unit commanders, to the controlling military police, and to engineers supervising the passage. Speeds are adjusted and assembly areas occupied and vacated at appropriate times to ensure continuous rapid forward movement.

The Corps commander moves forward. While the commander is airborne, sensors emplaced by special operations forces indicate the movement of a large tracked vehicle force. The Corps commander is alerted by an airborne communications system. At the same time, JSTARS reports a similar movement. Calling up the JSTARS track on his display, the Corps commander determines that it is probably a tank brigade previously identified in the area. He directs aerial surveillance and overhead imagery to confirm. The artillery commander and aviation commander are directed to coordinate an attack with long-range tactical missiles, an attack helicopter battalion, and tactical air strikes. Control measures are established to provide for troop safety and adequate separation distances; these are broadcast to all organizations in the Corps. The database is automatically updated and maps posted electronically. Scout helicopters operating with the armored cavalry units leading the attack are alerted electronically. Their on-board displays depict the enemy targets and the planned attack. Following the attack, the scout helicopters conduct battle damage assessment, providing imagery and direct readout to the Corps commander and all other involved commanders. Surviving enemy targets are handed off electronically to supporting artillery or other weapons that can engage.

Units converging on the battlefield are alerted to each other's presence automatically as the database is updated from position location sensors on combat vehicles and the radios of dismounted units. Battlefield combat identification sensors respond with coded identification of friendly vehicles when in the heat of battle they are spotted by the laser range finder of another friendly weapon. Targets are handed off from tank to tank or to attack helicopters, artillery, or close support aircraft.

As the attack proceeds deeper into the enemy, the situation becomes more complex and confusing. Vehicles break down or are damaged. Enemy units are bypassed. Unarmed support vehicles move forward to resupply or refuel the combat vehicles. Units deviate from planned routes as a result of combat, obstacles, or changes in plans. Automated position location provides continuous updates to the database and keeps units informed of unit locations. Commanders and supporters conduct automated queries without distracting the element being queried. Automatic coded identification signals minimize the likelihood of fratricide between friendly units. Commanders at each echelon determine what information they need and set predetermined criteria for alerts and prompts to avoid information overload.

After the battle is over, the same communications and electronic systems assist commanders in reassembling their units, assessing casualties and battle losses, completing resupply and repairs, and preparing for follow-on operations. Data from the battle are called up from the secure database to permit an assessment of the operation and lessons learned for future operations.

* * * * * *

The committee's analysis of the above scenario is contained in the following section.

ANALYSIS OF THE SCENARIO

The activities described in the preceding scenario are essentially the same activities that would be conducted in any operation, whether supported by automated systems and multimedia communications or by manual systems and messengers. The difference is the speed and accuracy of the information distribution, the continuous, automated update of the databases, the ability to coordinate actions simultaneously throughout the battlefield and inform all of those involved in real time, and the ability to free commanders and staff from the drudgery of repetitive and monotonous tasks. The effect on unit organizational structure and the tactics employed to leverage the advantages achieved could be dramatic. Smaller forces, widely separated, will be able to increase these combat effects simultaneously and at a vastly increased pace and tempo. Ammunition and logistics stockage levels can probably be reduced as support units maintain a real-time accurate knowledge of each unit's status and deliver the needed supplies on time and without requests. Smaller staffs employing automated systems and support aids will be able to coordinate the operations of more subordinate formations and provide more accurate and more timely support to commanders.

As the committee analyzed the scenario depicted above, it concluded that the gaps between current technological capabilities and what is needed to realize the future capabilities, as described, are as follows. The scenario implies an enterprise information architecture where data are a corporate resource that is shared by many applications. This sharing is a goal of many commercial enterprises. The technology challenges lie in transitioning existing legacy systems; building open and distributed computing environments that are secure and reliable enough; and provisioning and managing the capacity of information servers, processing resources, and communications facilities to assure that all needs are met in a timely way.

These are major challenges that will be addressed mostly by commercial technology trends. A principal focus for the Army should be on monitoring these trends and adopting best commercial practices. In addition, the Army should focus on creating and deploying an appropriate secure communications capability that can support battlefield needs and is compatible with the functionality and interfaces of communications capabilities that will be used in commercial enterprise information systems. A serious problem for the Army might occur if the battlefield communications capabilities were not able to support the communications requirements of higher layer commercial enterprise information system building blocks. This might result in the inability to leverage those COTS technologies and a corresponding major capability shortfall for the Army. The Army will also have to influence commercial technology trends to accommodate its unique security and access control requirements (if they are unique), as well as the serious network management challenges associated with multiple, simultaneous failures of equipment that can occur in battlefield situations.[3] Finally, the Army must create physical packaging technologies or influence commercial trends to accommodate its unique or more compelling requirements with respect to emissions of electromagnetic interference, resistance to nuclear radiation and EMP pulse effects, shock and vibration resistance, and ruggedness in general.

The committee emphasizes here the importance of performing battlefield activities securely, in a fashion that will protect critical information from the enemy and ensure that it is not corrupted by the enemy. When building an effective security environment that protects information while retaining ready access, it is essential that security be built into the communication architecture from the start. There must be a tradeoff between the speed of sharing information and the effort expended to protect it. For example, if the criticality of certain information will expire in a few minutes, it might be desirable to use commercial encryption schemes (e.g., the DES (digital encryption standard)) or other techniques such as frequency hopping. In cases where information must be absolutely protected for long periods of time, Army-specific mechanisms may be more appropriate.

This future scenario implies a great deal of automated information processing and filtering. This is also required in the commercial marketplace for such applications as electronic commerce (e.g., electronic shopping and advertising) and intelligent transportation systems. Technology for automatically indexing multimedia information objects, such as maps to facilitate searching and filtering, is relatively immature today. Although there are important commercial uses for such technology, this is an area where the Army may wish to invest in R&D to develop a competitive advantage over its adversaries.

As previously discussed in this chapter, the simulation capabilities described in the scenario represent an area of current Army leadership. The Army should continue to invest in robust simulation capabilities to maintain its competitive advantage. Also, the sensors, including satellites and unmanned aerial vehicles utilized in this scenario, represent areas where the Army (and more generally DoD) should continue to invest to retain competitive advantage.

Above all, the committee wishes to reiterate that it is the successful integration of all of these technologies into end-to-end applications, which work securely and reliably on the battlefield and are easy and intuitive to use for both commanders and soldiers, that represents the most important opportunity for the Army to retain its advantage over its adversaries.

SUMMARY

In this chapter, the committee showed how the building block technologies can be used to meet the Army's operational needs and functional requirements. The building block technologies and the needs and functional requirements were mapped onto one another. The chapter also outlined why it is desirable to have a technical architecture. An architecture provides a framework for information systems development that leverages the commonality between specific applications. The committee's multimedia architecture introduced in Chapter 3 was shown to correlate with the current Army architecture.

[3] An area that is not amenable to being addressed within the scope of this unclassified study is that of vulnerabilities of the systems envisioned in this scenario to major, simultaneous, unrecoverable disruption. The committee has mentioned such things as nuclear radiation and electromagnetic pulse (EMP) resistance requirements for physical equipment and the requirement to protect systems from various intrusions that can lead to denial of services. The committee has mentioned the importance of influencing trends in commercial network management technologies to accommodate graceful degradation in the face of multiple, simultaneous failures. However, the committee feels obligated to point out that much research, development, and experimentation is needed to create technologies, system architectures, operational methodologies, and doctrines that remove, reduce, and work around major system vulnerabilities associated with battlefield applications. These vulnerabilities represent major concerns in commercial applications as well.

Using the committee's multimedia architecture, the Army-specific requirements were shown to appear primarily at the bottom and top layers while the middle is typically filled with generic components.

The committee assessed each of the building block technologies and expressed its collective position on whether the commercial marketplace would drive the development of the technologies in a manner that would meet the Army's requirements. The committee's conclusions were offered as recommendations on whether the Army should adopt commercial technology, adapt commercial technology, or invest in producing its own technology for each of the building blocks to meet Army functional requirements.

A recurring observation was that the Army should use COTS technology wherever possible, even to the extent of redefining requirements in order to do so. These technologies are available in the commercial world now, or they will be available before the turn of the century. They can be adopted or adapted rapidly and relatively easily to many Army applications.

To illustrate how using commercial multimedia technologies could meet Army operational needs and functional requirements, an operational example was given. This example was followed by an analysis that indicated some of the challenges that will have to be met in order to achieve this futuristic state.

By following the approach described in this chapter and applying the technologies as recommended, the committee is confident that the Army can achieve a large part of its vision of the future.

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Corporate Reinvention in the Information Age

In the last decade it has become axiomatic that no corporation, no matter how large or how successful, is immune from upheaval or failure. In 1969, the number of Fortune 500 companies reporting losses was 11, in 1985 it was 70, and in 1994 it was 149 (Shapiro et al., 1994). In a similar vein, the fortunes of two-thirds of the companies applauded in *In Search of Excellence* (Peters and Waterman, 1982) have changed (The Economist, 1994). Many of these changes of corporate fortune have been in large part attributable to the failure of those organizations to assimilate new technologies effectively.

This chapter examines how information technology can transform a business in terms of how the business is done, its fundamental business processes, and how the business seeks to differentiate itself from its competitors. Based on lessons learned from such transformations in the commercial world, the committee then explores the implications for the Army.

INTRODUCTION

The initial focus of this chapter is on large-scale corporate reinvention aided by information technology. This focus provides an appropriate backdrop to the committee's belief that the Army will need to undergo large-scale reinvention to remain competitive with armies that can design themselves with the newest information technology or are less burdened by legacy systems and embedded industrial age processes.

To set the stage for what follows, the characteristics of reinvention, both as they apply in the corporate world and as they could apply to the Army, are described below. An overview is then provided for the remainder of the chapter.

Reinvention

The characteristics of a reinvention process are (a) a radical level of change in how the enterprise operates; (b) starting anew; (c) a time frame of several years; (d) broad, cross-functional scope; and (e) cultural and organizational change (Davenport, 1993). Reinvention can be contrasted with continuous process improvement, in which an existing process is gradually refined (e.g., stepped improvements in the 10 percent range). Unlike continuous process improvement, reinvention aims for several-fold improvements in organizational effectiveness as measured by productivity, customer complaint rates, rework, or combinations of these.

Reinvention is achieved by using radical business-process reengineering. In the corporate world, most radical reengineering projects were undertaken only when competitors were at the gates.

Reinvention of the Army is seen by the committee as also involving competitiveness, only here the competitors are the U.S. Army vis-a-vis the armies of likely opponents in warfare. However, unlike the corporate world, the Army cannot assume a reactive position; it must undertake planning and execution of a reinvention strategy before being confronted by superior hostile forces. The Gulf War experience may have some humbling aspects that could be used internally to motivate reinvention. At the same time, the evolving threats of the post-Cold War era with their requirement of short notice, rapid response to a variety of contingencies, suggest that the Army must reinvent itself with a range of lethal foes in mind. The Army's basic mission—the reason for being—is to win the nation's wars. That will remain its "raison d'etre," its "core business," but the Army's reinvention will surely change how it goes about accomplishing its mission.

Chapter Overview

The chapter makes three main points regarding commercial experience:

1. The large infusion of information technology in commercial businesses has greatly increased capabilities even though it has not as yet produced the anticipated gains in productivity.
2. To be successful, technological introduction must be accompanied by a change in the way work is done.

3. The chances of success for large-scale reengineering have so far proven to be small—roughly 25 percent. This dark side of reinvention exposes several critical factors (e.g., the culture and organizational structure must change to accommodate technological change).

The chapter also presents three case studies to illustrate important lessons learned from the corporate world. Finally, in light of the available data and accumulated wisdom in corporate America, the chapter addresses what can realistically be expected by the Army and in what time frame.

THE PRODUCTIVITY PARADOX

Despite computer power doubling every 18 months, whether this powerful technology has actually enhanced productivity has been hotly debated. It has been cogently argued that computers have had a negligible effect on productivity (see, e.g., Roach, 1991, 1992, and Strassmann, 1990). To quote Lester Thurow of the Massachusetts Institute of Technology (Thurow, 1991):

> Specific cases in which the new technologies have permitted huge increases in output or decreases in costs can be cited, but when it comes to the bottomline there is no clear evidence that these new technologies have raised productivity (the ultimate determinant of our standard of life or profitability). In fact, precisely the opposite is true. There is evidence, in the United States at least, that the investment in the new technologies has coincided with lowered overall productivity and profitability.

A recent book provides a digest of all the available cross-industry and cross-country productivity data (Landauer, 1995). Data show that computerization has had large positive effects on manufacturing by introducing computerized process control. Data also show that computerization has led to substantial gains in telecommunications industry productivity that have been sustained over a long period of time. However, for many industries, the effects have been negligible.

While it has been difficult to document that investment in information technology has improved important business outcomes (Strassmann, 1990), there have been examples of positive business effects. For example, there are several ways that computers can be used to increase productivity (Landauer, 1995):

- reducing redundant work by electronic storage and transport of information;
- improving coordination and synchronization of work by better planning, monitoring, tracking, and analysis;
- supporting products and services that depend on powerful information processing; and
- allowing people to do information work more efficiently.

Most of the successes are in the first category (e.g., reducing paper and data entry). Improved coordination and synchronization have occurred in the airline industry with route and schedule optimization and in overnight freight (see the case of Federal Express described below). Information retrieval systems such as Dialog are examples of the third category, and computer-aided-design tools are an example of the fourth.

For some industries, such as the airline, financial, and telecommunications industries, investment in information technology and its applications has been viewed as an ongoing part of the cost of doing business for a decade or more (i.e., a necessary investment to improve or retain competitiveness). In these industries, much of the investment to date has been in the communications and data-handling infrastructure.

Well-known examples include airline reservation systems, the banking automatic-teller-machine network and all wired financial transactions,[1] scanning systems for inventory in the retail industry, and the billing systems in the telephone network. Each of these mega-applications has changed the way business processes are done and would have been impossible without information technology. What characterizes many of these successful uses of technology are large transaction volumes with data that change frequently. *In all of these cases the software*

> The airline industry has put information technology to good use (NRC, 1994). Information technology is used to track departures and arrivals and schedules that change frequently. Today's airline reservation systems (with mind-boggling numbers of routes, fares, transactions, and people accessing the systems) could never have existed in a paper environment. Airline executives claim that the value of the airline reservation systems exceeds the value of the planes (NRC, 1994). Airlines also make extensive use of simulation for training and expert systems for maintenance.

[1] Banks process tens of billions of transactions a year. The Interbank Payments System handles approximately $2 trillion worth of transfers per day. The automatic teller machine network consists of more than 75,000 automatic teller machines in the United States alone and handles more than 6 billion transactions annually.

systems, not the hardware, have been the major investment.

Thus, the business case supporting the application of information technologies in industry, particularly service industries, has been mixed. While for many industries data supporting a return on investment in the form of cost savings or customer satisfaction from the substantial investments made in these technologies are disappointing, there are some major industries that have shown positive returns and have, in some cases, been substantially changed by information technologies. Successes to date have focused on data communications, data capture, and transaction processing technologies.

Although the effect on productivity to date may have been minimal in many industries, successful applications of information technology have made more and better information available, thus permitting improved planning and application of resources with the result of greater customer satisfaction. The implications for the Army can be significant if the Army employs information technology for similar purposes. Providing more and better information to those who need it when they need it and eliminating repetitive, redundant tasks should lead to better planning and the better application of combat power at the right time and place. The result may well be that a smaller, early-deploying force will have the capability to handle the contingency crisis it has been deployed to handle and to do so quickly with minimal losses.

SUCCESSFUL REINVENTIONS: CASE STUDIES

The current emphasis on reinvention and on business-process reengineering, as exemplified in *Reengineering the Corporation* (Hammer and Champy, 1993), is attributable in large measure to the demonstrated success enjoyed by businesses that have changed processes to make best use of technology. To illustrate some lessons learned from successful reinvention, the committee considered three corporations that have reinvented themselves aided by information technology. Each offers somewhat different insights and applicability to the Army.

Citicorp

Citicorp was a classic successful, large, insular company, which found itself in a time of rapid change when the ability to learn, adapt, and move quickly was key to survival. Banking had become highly competitive with constant pressures to reduce costs and to innovate. Citicorp realized that it could not afford to do everything internally, that many things had to be outsourced, and that other ventures had to be the products of alliances. While Citicorp employs a large number of technical people, it is not a technology company, per se, except in one area—analytics. Analytics includes the science of credit, market, and risk analysis; customer modeling; data mining; and portfolio management. These are the corporation's crown jewels—the science that allows it to look for new opportunities in the market and evaluate their risks (Schutzer, 1995).

CITICORP: REDEFINING BANKING AS SUPERIOR RISK MANAGEMENT AND CUSTOMER SERVICE ACHIEVED THROUGH SUPERIOR INFORMATION SYSTEMS

Citicorp brought the workstation environment and corporate information to virtually every employee with resultant large productivity gains. Citicorp also has been restructuring its business, outsourcing more noncritical business functions and dramatically downsizing its work force.

Key Lessons

- Outsource noncore business functions.
- Retain technological leadership only in core business areas.

Army Correlates

- Use commercial off-the-shelf (COTS) technology, except in carefully targeted areas where the Army can obtain a differentiating advantage.
- Only develop technologies to meet Army-unique needs.
- Outsource as many requirements as possible.
- Focus on the Army mission—to win the nation's wars—and apply information technology to change the processes that lead to battlefield success.

Citicorp has been actively restructuring its business since the mid-1980s by redesigning its work flow and systems to exploit information technology. Moving to a single integrated and interoperable corporate network has produced enormous cost savings through efficiency gains, amounting to approximately $100 million annually. Also, computing technology, including tools and databases, was moved to the desktop. Virtually every employee was given a workstation and access to corporate-wide information, which established linkages between the work groups and the enterprise. Technology was used to streamline work processes, pushing decision making lower in the organization and reducing duplication of effort. In addition, using computational tools allowed employees to get work done faster.

Citicorp systematically measured the effects of its business-process reengineering in its Real Estate Group. As cited in Tapscott and Caston (1993), two years after the business-process reengineering, the amount of time to process loans had been reduced by about 50 percent, profit center earnings had more than doubled, executive time spent on "administrivia" had been reduced from 70 percent to 25 percent, and the number of customers per account executive had gone up by 170 percent.

Federal Express

Federal Express is frequently cited as the premier example of an integrated, enterprise-wide organization, delivering 1.5 million packages a day with a goal of 100 percent timely and correct delivery. The Federal Express network has 420 airplanes, 30,000 trucks, and almost 100,000 people working in synchrony. Innovative use of information technology is the cornerstone of Federal Express business (NRC, 1988).

By using real-time tracking and tracing systems networked together, Federal Express "knows" where every package is instantaneously. Barcodes on each of the 1.5 million packages are scanned an average of nine times. Federal Express constantly runs software to determine if shipments have gone astray and to try to correct the problem before the customer is affected. The chief information officer at Federal Express has stated, "We believe that information is just as important as the shipment. It provides a tremendous amount of product differentiation and value added to our product" (Tapscott and Caston, 1993).

FEDERAL EXPRESS: REDEFINING FREIGHT DELIVERY AS CUSTOMER PEACE-OF-MIND ACHIEVED THROUGH THE USE OF INNOVATIVE INFORMATION SYSTEMS

Federal Express successfully implemented an enterprise-wide tracking and monitoring system for its packages, which stemmed from the realization that knowing the location of a package was as important as the shipment itself. The Federal Express system development story underscored the need for iteractive design and development: "We won't get it right the first time, but we will come back and fix it" (NRC, 1988).

Key Lessons

- Spiral development (i.e., use iterative design and development methods).
- Innovative application of technology can achieve a desired commercial outcome.

Army Correlates

- Experiment (e.g., via simulations).
- Focus on the application of technology to achieve desired military objectives (e.g., situational awareness, on-time delivery of munitions, supplies, support), not the technology itself.

The Federal Express system, COSMOS, was first implemented in 1977 and gained the functionality described above by approximately 1988 (NRC, 1988). During that time Federal Express field-tested numerous custom-built scanners, working with one vendor for 3 1/2 years to develop a scanner that met all the business needs. With the in-house expertise of dealing with a hardware vendor in place, the next hardware scanner project was accomplished in 1 year. The current system—COSMOS, IIB—had its share of redirects and restarts, testing many different versions of the scanner as well as different networks and software, but it is considered to be a very well-managed project. The evolution of the Federal Express system is an excellent example of successful spiral development.

Ford

In the early 1980s, Ford was losing market share to the Europeans and Japanese in the automotive business. In 1980, Ford lost $1.5 billion. It was clear that Ford's basic survival was at stake, and the corporation undertook to dramatically change the corporate culture and business. That turnaround is usually attributed largely to Total Quality Management rather than to technological innovation as in the Federal Express story. However, the problems Ford faced are pervasive in any old, large, vertically integrated business, including the military.

Ford's biggest problem was that it was not producing nearly as good a car as its competitors—the same car assembled in the United States was inferior to the one assembled in Japan. Ford initiated a no-holds-barred employee involvement program. Decisions on how to improve production were pushed down to the rank-and-file workers. Management levels were eliminated, and all managers were trained in participatory management. By constantly monitoring the product and the process and keeping people involved as team members, Ford was able to regain market share (Petersen and Hillkirk, 1991).

Initially, Ford changed the business by making incremental changes—continuous quality improvements. After a few years, the marginal effects of this more gradual process became negligible. Improvements at the next stage required radical redesign of the basic business processes, as illustrated by the overhaul of the procurement process described below (Hammer and Champy, 1993).

FORD: REDEFINING ITS AUTOMOBILE MANUFACTURING OPERATIONS AS PRODUCT QUALITY ACHIEVED THROUGH MAJOR PROCESS REDESIGN

The Ford Motor Corporation made a significant turn-around in the 1980s. Much of its success can be attributed to continuous quality improvements and participatory management techniques. Ford's redesign of its accounts payable department, dramatically reducing the number of people involved, is frequently cited as a reengineering success story.

Key Lessons

- Flatten the management hierarchy for efficiency.
- Use benchmarking to overhaul a key business function.

Army Correlates

- Reexamine the command and control hierarchy, with an eye toward opportunities for substantial streamlining and changes in functions.
- Benchmark against other organizations to stimulate bold thinking about process reengineering opportunities.

Ford's accounts payable department employed over 500 people in the early 1980s. By straightforward computer automation of their functions, Ford believed that a 20 percent personnel reduction could be achieved. On a visit to Mazda, however, Ford executives found *five* people doing the accounts payable function. This discovery prompted Ford to look beyond redesigning what the accounts payable department did to redesigning the entire procurement process. To quote Hammer and Champy, "Define a reengineering effort in terms of an organizational unit, and the effort is doomed."

In redesigning the process, the traditional three-part invoice was eliminated. In its place was a much more streamlined process: (1) Buyers enter a purchase order electronically, which simultaneously goes to the vendor and an internal database. (2) When the goods arrive at the receiving department, receiving takes possession of an order that is in the database and, upon accepting it, causes a check to be issued and sent to the vendor. (3) Orders not in the internal database are shipped back to the vendor—simple, efficient, and cheap. Now, routine payments are a part of the process of receiving goods, and an accounts payable group consisting of only a few people exists to handle exceptions.

THE DARK SIDE OF REINVENTION

There is a significant danger when writing about corporate reinvention (also referred to in the literature as reengineering) to highlight the success cases and down-play the failures. But in fact there have been far more abortive efforts than successes, with an estimated success rate of only 25 percent (Landauer, 1995). The literature quickly becomes redundant; the same examples are used time and time again. An impression can be created that reinvention is easy: obliterate and start over; a bit of creative thinking will solve most business problems. Instead, a successful reengineering project requires many rare ingredients, a master chef, and some highly skilled *sous*-chefs.

The next wave of popular-press books may proclaim reengineering as practiced thus far to be the black plague of corporate America. Corporate America has bought the reengineering dream wholesale and downsized the work force, banking on success. However, when reengineering projects are not successful, the results are: the requisite expertise to run the business is gone; the quality of the product or service is undermined; and the business begins a downward spiral. The Army cannot afford similar results.

With this frequent failure in the forefront, the committee analyzed those factors that are critical to consider when deciding whether or not to reengineer. These factors are:

- Radical reengineering requires careful scrutiny of existing processes to identify those that must change and to evaluate critically the probability of success.
- Most successful efforts start from a small core and build outward.
- Highly skilled managers and staff are needed to implement most ambitious plans.
- Finally, the culture and organization must change to accommodate technological change.

Each of these factors is discussed below.

Not Every Business Process is a Candidate for Reengineering

Decisions on whether or not to reengineer a process or a system should be based on honest answers to some hard questions: Does a significant cost reduction in this process need to be achieved for the business's viability? Does this process constitute a competitive niche or market differentiator? For example, not all legacy systems have to be replaced. In fact, analyses of some legacy systems might reveal that the cost of replacement is more than the expected gain. Not all business processes are of equal importance. For most businesses, those processes that are directly perceivable by the customer are the first to scrutinize as reengineering candidates. Federal Express was missing critical deliveries (its core business) and hence decided to redo its tracking system. Banks have concentrated on customer services, such as making automated teller machines available and easy to use (the core business). Banks have outsourced back-room functions that are not their core business (e.g., Banc One hired an outside company for data processing and Citicorp formed an alliance with another company). The cutting-edge technology should be applied in areas where it is a market differentiator.

Start Small and Build from Success

It is tempting to move to a utopian mode when undertaking reengineering (i.e., every process would be better off being dismantled). However, to undertake multiple projects simultaneously that are interdependent in function and sequence is to court disaster. Most reengineering depends on software being built, and it is well known that large software projects are typically in crisis mode. Undertaking multiple reengineering projects invites all the unsolved problems of software engineering in the large; coordination and information-sharing difficulties increase with the square of the number of people and software interfaces that need to be maintained. Small is beautiful in software and so too in reengineering. Most reengineering projects that succeed follow iterative software engineering methods. They start with a core functionality, refine it, and build outward in quick design and implementation intervals. The benefits of iterative design cannot be overestimated, and it becomes more important as the complexity of what is to be implemented increases. Landauer (1995) documents the benefits derived from iterative methods with actual project data. One such iterative method, a thorough round of evaluation and redesign known as User Centered Design, resulted in improvements per design cycle of as much as 720 percent. As a rule of thumb, each design cycle is likely to improve performance, as measured for a particular application, by about 50 percent.

Inexperienced Staff and Managers Need Not Apply

Many reengineering projects fail because they are staffed with people having inappropriate skills. In the experience of the committee, one needs extremely talented software engineers who can design and implement quickly and effectively. The best programmers are 20 times more productive than average ones (Egan, 1988 and Pressman, 1994). However, these experts need to be supported by people who understand the systems they are replacing and who understand the business needs. A team composed solely of software experts will fail, as will a team composed only of people who wrote and maintained the systems that are being replaced. There needs to be a working partnership with roles and responsibilities strongly defined and enforced. In point of fact, there are too few software engineers who have completed successful reengineering projects; there are even fewer managers who are current with the technology, understand the business needs, and have actually experienced reengineering successes. In terms of the rare ingredients, the most important one is having the critical skill sets in terms of the people doing the reengineering: subject matter experts familiar with the domain; software engineers with domain expertise and a reengineering success, if possible; and technically skilled managers who are current with the technology to be used and have managed a previous reengineering project.

Cultural Changes and Support for the Change

Davenport (1993) points out that information technology can only enable; to be successful it must be accompanied by organizational change. To benefit from new technology, the nature of the work to be done must change as well.

Dependencies similar to the interrelation between process innovation and technological innovation exist with cultural change; social and technical change must go hand-in-hand. Many a reinvention attempt has failed because the existing corporate culture was not ready for the change or because no one understood just how much the culture would have to be changed to accommodate reinvention. Davenport (1993) discusses cultural enablers of radical corporate innovation: (a) empowered employees, (b) active participation of employees in decision making, (c) open communication channels, and (d) flatter hierarchical structure. So, as the list implies, a receptive culture is one in which communication across functions and between levels is welcomed and is active, dynamic, and participatory. Unfortunately, most corporate cultures are characterized more by their rigidity and inability to change, and this makes radical innovation nearly impossible. Davenport (1993) has observed that the most difficult task many corporations face in radical redesign is getting the senior executives to act as a team. In many organizations, senior executives control fiefdoms with little desire or need to communicate, let alone cooperate across functional lines. However, the result of a successful reinvention is massive organizational rearrangement, frequently combining once-separate functional entities as well as overall streamlining. So, when turf retention is an issue, executives may consciously or subconsciously undermine a reinvention effort.

To reinvent basic processes using information technology, the nature of the jobs performed must change. This change is very threatening to those employees currently doing the old jobs, and those employees may be a source of sabotage. Very often the new plan calls for new employees, since the embedded base of employees does not have the right skill set. Thus, the new agenda is in direct conflict with what the employees perceive to be their best interests, and so a battle of organizational survival versus employee survival can ensue.

Somewhat related to the above issue is the question Who is going to implement or build the new design? Hammer and Champy (1993) as well as Davenport (1993) stress that bottom-up reengineering does not work. However, there have been instances in which a top-level design and initial implementation has been done but then was severely compromised because the wrong implementation team was selected. In a particular case, the reengineered design called for looking at products the business sold in a fundamentally different way from the way the business currently operated. However, the implementers were so involved in the old way of thinking that at every turn in implementation the design was compromised, thereby systematically reintroducing concepts that had been killed in the radical redesign. Further, these design compromises were made unwittingly; the familiar way simply made more sense to these people.

Change requires champions, and not just a single champion. Given the rate of job changes in the average business and the duration of most reinventions (2–3 years), it is likely that a single champion will have come and gone in that time. Also, social acceptance of new ideas requires multiple committed spokespersons and corporate "movers and shakers."

IMPLICATIONS FOR THE ARMY

This section contains the committee's views on how to apply some of the above lessons learned in the commercial sector to the Army. It has been written from the perspective of information technology and is not meant to suggest an overarching roadmap for reform of the Army as an institution.

The following sections focus on (a) what has been learned in commercial experiences with reengineering that is relevant to digitizing the battlefield and (b) an overview of the effects reengineering is likely to have on the Army.

Digitizing the Battlefield

The problem of displaying the relevant command and control information in a way that is highly usable to each soldier and commander on the battlefield needs to be solved using iterative methods. The questions What is information in this context? and How easy is it to make the correct interpretation? are interface and usability issues that can only be resolved by putting the technology in the hands of the users and iteratively refining the design. This is an opportunity for multimedia to impact battlefield events favorably, if used effectively, but it is an invitation for disaster if done poorly.

In terms of overall cost, a rule of thumb is that the system software costs at least three times as much as the hardware. Given the inherent complexity in the Army applications, it is all the more important to use iterative software design and development methods rather than counting on one giant leap forward. In addition, the success rate for large software systems and reengineering projects (one in four succeeds) is low, implying that the Army cannot afford to use less than the best practices and methods in systems development.

Effects of Reinvention on the Army

It is obvious that information technology resides at the heart of the vision for the Army of the future. What is less obvious is how information technology will transform warfare and how the Army must transform itself to best benefit from technology. This chapter has stressed that it is wrong to believe that just the technology changes. To effectively use technology means that the work, the organization, its doctrine, and the culture all must change. Moreover, because the Army's vision of the future relies on the massive infusion of technology for acquiring, processing, and communicating information—technology that will change the organization and how it functions—one cannot comprehend as yet what the future Army will be like organizationally or how its battles will be fought.

Processes and work flow in unit staffs will change. Simply automating current procedures will not leverage the full potential of information technology. If staffs are not reduced, automation may have a negative impact as large staffs find more time and automated capabilities to demand more information from subordinate organizations.

The Army will have to analyze the role of staffs in the information age and the functions they perform. That they can be smaller is certain, but they are also likely to be restructured.

The committee's review of corporate success stories also indicates that it will be possible to eliminate one or more levels of command. As commanders, supported by smaller staffs, are able to command and control more subordinate units effectively, organizational structures can evolve into flatter, more integrated, and less vertical entities. The Army will have to review the purpose served by each level of command and the value added to the overall success of the enterprise. Corporate experience indicates that failure to eliminate intervening levels is a mistake. Often, levels between the decision maker and the executor of a function become redundant and an impediment to efficient operations.

Operations can take place faster and be synchronized over a wide area with the application of advanced information technologies. The implications for Army doctrine and tactics are likely to be extensive. Units will be able to move rapidly, operate with greater certainty, and make more rapid decisions. Exactly how the tactics will be affected may not yet be evident, but corporate experience again makes it clear that those who fail to assess the fundamental ways an enterprise conducts its business and to adjust to new ways will not leverage the advantages of information technologies and are likely to lose their competitive advantage.

Extrapolating from the success stories in the corporate world leads to the recommendation that iteration and experimentation be built into the process from the beginning. It is beyond the limits of human intellect to come up with the grand master plan that will effectively transform the current Army into the future, information-based Army. Success is made with plans of limited scope that are intended to be built, tested, redesigned, and expanded. At the core of effective use of information technology are iterative design methods, which were best exemplified by the Federal Express story. Despite 20 years of crisis and large-scale failures in the software industry, there is just beginning to be an understanding that requirements are always incomplete, that the first implementations are always flawed, and that reducing development time in software must translate into shortening the time through successive cycles of design, implementation, and evaluation.

Fortunately, the Army has a leg up on many of its industrial counterparts in experimentation, as it has a rich tradition of using modeling and simulation to aid decision making. These same technologies can be used to reduce the risks of reengineering. For example, the Air Force plans to use simulation, modeling, and work flow computer tools to enable decision makers to better predict the impacts of incremental-to-radical changes in business processes (USAF, 1995).

Given the risks and uncertainty inherent in reengineering, it is very important to identify processes that are key to success and to benchmark them formally against external corporations or institutions. To do this effectively requires a critical examination of the internal operations together with an assessment of the outside competition or industry leaders in a particular area of interest. After unearthing best practices, the organization must figure out how to assimilate these into its operation. Formal benchmarking is a disciplined process of uncovering and measuring effects of adopting best practices.

Done correctly, digitizing the battlefield is a complex systems integration job, which will need much experimentation and refinement. Thus, the role of the Battle Labs will become even more critical and will probably expand in coming years as a means of quickly evaluating new technology and introducing it into the evolving systems. In addition, realistic field testing of the complete system at frequent intervals, through exercises such as the Louisiana Maneuvers and warfighting experiments, will be essential to not only see that the technology works but to understand how the work must change to use the technology. Much of the active interplay between technology and work must be seen and experienced in order to know how to modify each component. These are difficult things to visualize.

Another important aspect of active experimentation is to find out just how usable and useful the information technology is. The lesson over the past few decades is that it has been tremendously difficult to invent software that improved end-user productivity. In a battle situation in which stress, fatigue, and attention overload operate, it is more important, yet more difficult, to build usable systems. Unfortunately, there are few principles to guide correct design. The state-of-the-art is to do usability evaluations in multiple phases of development and in each product or system release.

The recommendation to use open systems and components, which plug and play, has been made several times in this report. There are large gains to be made in such areas as development time evolving to new systems and levels of expertise needed to accomplish specific tasks. Again, the use of open systems and components are examples of how iterative reengineering can be accomplished.

Perhaps the biggest unknown is how the Army will look and feel as an organization in the twenty-first century. In the successfully reengineered businesses, there were fewer people running the business and more integrated organizations (e.g., fewer vertically integrated functional entities). More of the workers became generalists, but in many cases the jobs demanded more education and training than previously. The Army may find that a new kind of warfare demands more technologically sophisticated enlisted and officer personnel and that the current skill inventories are underrepresented in disciplines that support computer applications and communications technology.

If the cultural enablers of reinvention are the same as in corporate America, the committee speculates that the cultural transformations that need to occur will be the Army's biggest hurdle. Warfare is not management by consensus. Hierarchies exist for the efficient flow and control of information. People need to expedite orders. Much of the organizational rigidity of the Army is there for good reasons—in times of conflict and confusion, what to do and to whom to listen need to be reflexive. How to overlay this on a culture that needs to have more open involvement, discussion, and evaluation of new ways of working will require that people understand that they have contradictory roles depending on the context. The committee does not expect the Army to abandon completely its chain of command orientation, but it does expect that the Army will need to accommodate a more empowered soldier and subordinate leader if information technology is to give the Army a competitive edge.

Cultural change also is likely to be resisted by senior executives, officers, and employees who, like their civilian counterparts, feel threatened by loss of turf or position. As has been noted many times in this report, to achieve the full potential that information technology offers, there must be fundamental changes in how the Army is organized and operates. Organizational changes, functional changes, and changes in work processes ultimately will affect the Army's basic branches, its senior commands, and its staff relationships. The natural inclination of those affected will be to resist changes that diminish the role, importance, or size of these entities. If the Army's efforts to reinvent itself for twenty-first century warfare—enbodied in Force XXI—are to be successful, the senior leadership of the Army must overcome the resistance that is almost certain to arise. Corporate experience makes it clear that this requires their personal and continuous involvement, including the "CEO," working collectively as a team.

SUMMARY

While overall there has been an apparent productivity paradox associated with the introduction of information technology, there have been successes as well. For example, information technology has made possible the coordination and synchronization of complex events, such as airline reservation systems.

Successful corporate change seldom results from technology alone; the business processes and the structure of the organization usually change as well.

Three successful corporate reinvention cases considered relevant to the Army were discussed. These cases involved the use of information technology at Citicorp, Federal Express, and Ford. Key lessons learned included the need to outsource noncore business functions, use spiral development, and flatten management hierarchy for efficiency. Corresponding Army correlates were: use commercial off-the-shelf (COTS) technology, except in carefully targeted areas; experiment (e.g., via simulation); and reexamine the Army's command and control hierarchy, with an eye toward opportunities for substantial streamlining and changes in functions.

Only about one in four reengineering projects succeeds. Among the many ways they fail are: (a) reengineering processes or business functions that are better left alone, (b) not starting small and building from success, (c) not having the critical skill sets available, and (d) not being able to change the culture to accommodate reengineering.

Implications for the Army, based on lessons learned, were then discussed more generally, beyond the Army correlates to the lessons learned in the case studies. These included possible changes in organization, doctrine, and tactics as well as the need to actively experiment and iteratively design and develop. No one has the blueprint for warfare in the twenty-first century—it must evolve. Not only is the technological end state unknowable at this time, but the cultural changes that will ensue are equally difficult to predict and will result from the interplay of the work, the technology, and the social structure.

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Technology Management Strategy

This chapter of the report describes a technology management strategy by which the Army can most successfully leverage multimedia information technologies for battlefield applications. The chapter is directed at Army decision makers who must translate goals and advice into action as they define and implement the Army's strategic plan for information technology management during the next several years.

INTRODUCTION

Although some of the recommendations presented in the following sections echo recommendations that have been made before (Howard et al., 1994) and have also appeared in high-level vision statements made by the Army's top management (Frankel, 1994; Frankel et al., 1995; Sullivan, 1994), the committee feels that it is essential to reiterate these recommendations because (a) the committee wishes to add its weight to these recommendations in the hope of accelerating their implementation; (b) the committee wishes to provide specific support for these recommendations in the context of applications of multimedia information technology; and (c) the committee is concerned that these recommendations are not being implemented aggressively enough to achieve the desired outcomes.

BE A HUNTER-GATHERER OF TECHNOLOGIES

In Chapter 3 of this report the committee provided an overview of 17 building block technologies that can be used to create multimedia information systems in a wide variety of generic application domains. In Chapter 3 the committee also gave examples of how multimedia information technologies are being applied in commercial cellular and wireless communication systems, electronic commerce, intelligent transportation systems, and residential information services. These commercial applications represent a worldwide market that is 10 to 20 percent of the gross domestic product of developed and developing nations (i.e., trillions of dollars annually). Thus the committee made an argument that it is unimaginable that Army research and development (R&D) efforts could be the driving force behind most of the building block technologies that support these applications. The committee identified specific areas where the Army's needs are sufficiently different from those of generic commercial applications and where the Army could focus its R&D initiatives in order to produce a competitive advantage for itself.

Based on these observations, the committee believes that the Army must seek out and acquire the best technologies wherever it can find them to meet its overall strategic objectives, and it should apply them in an opportunistic fashion to meet the demands of the battlefield. Most important, the Army must focus on leveraging commercial off-the-shelf (COTS) technology to achieve the rapid deployment of those technologies in highly effective applications, ahead of its adversaries. It must refrain from setting rigid requirements and specifications that imply a need for technologies that do not exist and corresponding development activities that will slow down the deployment of applications. There must be an iterative process by which requirements are traded against technical feasibility, with *time-to-deployment* as a key parameter to be optimized.

In the commercial world, the concept of time-to-deployment highlighted above is known as "time-to-market." Commercial firms have recognized that information technologies evolve quickly, that advantages over competitors are short-lived, and that a critical success factor in deriving advantages from information technologies and in competing in the marketplace is the speed at which new capabilities can be deployed.

Commercial firms have moved away from a vertically integrated structure and toward a horizontally integrated structure (as described in Chapters 3 and 5) in order to focus on those areas where they intend to differentiate themselves from their competitors. They have become hunter-gathers of technologies by purchasing technologies they might have previously developed themselves and by forming alliances to gain access to technologies they need, as discussed in Chapter 3 under Leveraging Commercial Off-the-Shelf Technology.

The Army must follow the lead of the commercial world by differentiating itself from potential adversaries via the speed and efficacy with which it deploys technologies in Army-specific applications and not, in most cases, by the technologies themselves.

In order to utilize COTS technology acquired in this mode to the maximum extent possible, it is essential that the Army's physical layer platforms (i.e., physical wireless communications capabilities, physical computer terminals, and other physical processing, storage, and display subsystems) be capable of supporting the COTS software that must be layered on top of these physical platforms in accordance with the Army's layered technical architecture. As an example the Army should focus on physical packaging technologies that will allow computer terminals, storage subsystems, etc., that are developed in the commercial world to be directly utilized in Army battlefield applications by applying this protective packaging. This would be an example of adapting COTS physical layer technology. As another example (stated previously in Chapter 4) the Army should create a wireless battlefield communications capability, based on such things as unmanned aerial vehicles (UAVs) acting as battlefield cell sites or repeaters that have capabilities comparable to those of commercial wide area wireless communications systems, so that commercial applications that depend on those capabilities can be directly applied to battlefield applications.

TARGETING INNOVATION

It is essential that the Army target its limited R&D investment resources on those aspects of information technology where (a) the Army has unique requirements, and (b) there is reasonable probability of obtaining a competitive advantage from R&D investment.

The existence of a gap between requirements that the Army may wish to meet and the capabilities of available commercial or Army-specific technology may not be sufficient to justify an R&D effort by the Army to close that gap. In many cases, a similar gap will exist between the requirements of commercial applications (i.e., unmet commercial market needs) and the capabilities of existing technologies. Examples include multimedia database management systems, graphical user interface technology, and distributed computing environments and operating systems. In those cases, commercial firms are likely to invest heavily in R&D initiatives to close those gaps, which raises the question of whether Army-specific R&D initiatives will result in any competitive advantage for the Army. In those cases, Army investment will often be better spent on participation in standards activities and perhaps in joint activities with commercial firms to improve the alignment of emerging commercial technologies with Army needs. In addition, the Army should closely monitor commercial trends and developments, including the successful or unsuccessful commercial application of emerging technologies, in order to maximize the timely and effective insertion of emerging technologies into Army applications.

In those cases where an Army requirement has no commercial counterpart, or where the commercial counterpart represents a small potential commercial market opportunity, it is possible that R&D investments funded and led by the Army may lead to innovations that place the Army at a competitive advantage (e.g., adaptive antennas for interference or jammer suppression in wireless networks). since there is no large commercial market opportunity driving the same innovation, it is less likely that the Army will find its R&D results overtaken by commercial results in the same area. Nevertheless, the Army should closely monitor commercial market trends, including trends that may be proprietary (and therefore require appropriate nondisclosure agreements) to assure that the Army is not duplicating larger commercial R&D efforts. It is essential that Army innovations be inserted into the overall Army information technology architecture in such a way as to facilitate the future insertion of commercial technology in the event that superior commercial technology emerges. This typically implies the use of a carefully layered technical architecture. In addition to focusing on the creation of carefully targeted activities to create multimedia information technologies where the Army can expect to produce a differentiating advantage for itself over its adversaries, the Army should focus on the innovative application of generic multimedia technologies to battlefields with an emphasis on time-to-deployment as discussed above.

BALANCED PROCUREMENT PROCESS

The committee believes that the Army must achieve a better balance in its procurement processes for systems based on information technologies between the imperative of making procurement fair and competitive and the imperative of successfully and effectively meeting time-to-deployment objectives for technologies which have life cycles as short as 18 months.

Commercial functional specifications are initially established as part of a business plan based on market analyses and tradeoff studies. Those initial functional specifications are often modified based on new information regarding customer needs and existing or emerging competitive products. Such decisions are based on return on investment and time-to-market considerations. Modifications to functional specifications are made in order to achieve overarching business objectives, and system or application-specific requirements may be translated to more general purpose requirements to facilitate potential software reuse. The general-business strategy is one of bringing products to the marketplace as early as possible, followed by evolutionary upgrades to provide additional capability or significant cost savings.

Vendor selection in the commercial world is not always based on the lowest-cost bidder. Best values are often negotiated as a result of tradeoffs of cost, the ability to meet requirements and to deliver product in a timely fashion, and the estimated risks in meeting commitments. Consideration is given to the mutual best interest of vendors and buyers who may operate in long-term teaming arrangements. Vendors are encouraged to offer best solutions, which may not meet 100 percent of requirements.

During the system development process, vendors often tailor existing products to meet requirements, and there is widespread use and reuse of COTS software in order to minimize costs and development time. Systems are designed to fit into a defined product or product line architecture to achieve commonalities that foster reuse of technology. Prototyping is commonly used early in the development process to refine requirements and to validate the vendors understanding of the buyers needs (see Chapter 3, under Adopting a Spiral Model). Joint customer and development teams work to clarify requirements and incorporate new requirements when there is minimum impact on cost and schedule.

In summary, commercial acquisition practices are based on flexibility and tradeoffs of requirements versus cost and schedule. They very often involve a team approach to system development. And they are strongly oriented toward reuse and tailoring of existing systems. An underlying philosophy is to anticipate product improvements and provide for their accommodation in the initial system release.

The lesson to be learned from commercial practice is that the Army acquisition process needs to be flexible. It needs to accommodate technologies that are changing as an acquisition is under way. It needs to be flexible to accommodate complex tradeoffs between cost, technical feasibility, target requirements, and time-to-deployment, many of which are not fully understood even at deployment. It needs to foster a partnership between the supplier and the purchaser where the focus is on meeting the Army's needs to deploy systems that are superior to those of its adversaries and to upgrade those systems over time to maintain that superiority. It cannot be based on rigid requirements set at the beginning of a procurement, which may drive up costs and delay deployment of needed capabilities far beyond any associated benefits of meeting those rigid requirements.

Setting rigid requirements for systems years in advance of their likely deployment will result in the deployment of obsolete technologies (owing to the rigidity of specifications that imply specific technologies or preclude the use of innovative new technologies) with their associated cost and performance penalties. Opportunities will be lost to deploy capabilities that were not believed to be feasible at the time the requirements were set. Efforts and resources will be wasted in the development of Army-specific technologies to meet requirements that could have been satisfied more opportunistically by existing or emerging commercial technologies at lower cost and with higher performance in most, if not all, relevant parameters.

ESTABLISH AND ENFORCE AN ARCHITECTURE

In Chapter 3 of this report, the committee introduced a generic multimedia architecture that provided a conceptual framework for describing the building block technologies that were discussed. Chapter 3 also described some lessons learned in the commercial world on both the advantages of establishing and enforcing a technical architecture and on the difficulty of doing so. The committee also noted the difference between a framework architecture and a specific, enforceable technical architecture.

A specific, enforceable technical architecture must define the specific building blocks that are to be used to build information systems throughout the enterprise. When more than one building block alternative is allowed, the documentation supporting the architecture must specify the conditions under which one or the other alternative is to be chosen, and it must specify how interoperability will be achieved by systems that utilize different alternatives.

The advantages of developing and enforcing a technical architecture were discussed briefly in Chapter 4. Specific advantages include interoperability; reuse of the building blocks, modules, and objects; insertion of new technologies; and facilitation of ad hoc modifications.

Interoperability

When systems employ the same building blocks, or where interoperability concerns between heterogenous building blocks are considered in advance, it is far easier to interconnect systems and to have them interoperate without extensive, costly, and time consuming development of new interfaces between systems. For example, if systems employ a common packet communications protocol like TCP/IP, then one system can easily transfer data packets to and from another system using the same packet communication protocol. If systems employ the same database management systems, then they can more easily access each other's data (although a common database management system is not sufficient for data sharing). If systems represent multimedia information in the same formats, and if they attribute the same meaning to the same names for information objects, then they can easily share information in abstract form without the need for translation.

Reuse of Building Blocks, Modules, and Objects

When systems conform to a common architecture and employ standard building blocks, it is possible to reuse the functionality of building blocks, and the modules and objects within building blocks, across multiple systems without having to redevelop them multiple times. Thus a database management system, and specific data structures that are created to perform a map management function, for example, can be reused in other systems and applications that require map management functions.

Insertion of New Technologies

When systems conform to a well-defined, layered architecture, it is possible to upgrade various building blocks independently to take advantage of new technologies. For example, if security functions are modularized properly in the design of the architecture and in its implementation, then a newer encryption method can be readily inserted without requiring the redesign of all of the building blocks to accommodate changes that would otherwise "ripple" through the entire system. A new method of providing wireless communication can be inserted into all systems without disturbing the functionality that draws upon that layer of the architecture.

Facilitation of Ad Hoc Modifications

When systems conform to a well-defined technical architecture, one can make rapid ad hoc modifications to the deployed system or systems to meet unforeseen needs. Thus, communication paths between systems or applications that were not foreseen can be added as needed in nearly "real time." Access to information by a commander that was not foreseen as a mission requirement can be quickly implemented if the appropriate access control permissions are granted. This property of "kludge-ability" has been recognized as an important benefit of information systems that conform to a well-defined technical architecture (Defense Science Board, 1994).

Management Issues

While all of these advantages of a well-defined and enforced technical architecture are well known and have been articulated before, and while the committee is aware that the Army has taken steps toward creating a technical architecture for the digital battlefield with Version 3.1 of the C^4I Technical Architecture (Department of the Army, 1995), the committee is concerned that the speed at which such a technical architecture will be developed and implemented may not be fast enough to satisfy the needs of Force XXI.

The committee notes that one of the biggest management challenges in implementing an architecture is in creating the incentives for suppliers and program managers to transition to that architecture. An architecture produces strategic benefits (as articulated above) for the Army as an enterprise. However, for any individual program, particularly the first programs that conform to the architecture, there may be tactical reasons not to conform. A particular program may find that it is more costly to implement the architecture because it cannot benefit from such things as reuse of existing functionality until the architecture is widely implemented. The architecture may initially be unfamiliar to the program manager and its suppliers, and there is a temptation to find excuses for bypassing the architecture to meet shorter term or tactical objectives.

Thus the committee urges the top management of the Army to put in place incentives for program managers and suppliers to conform to the architecture as it emerges. The committee also recommends that the Army increase the number of technical experts who are involved in the creation of the Army's technical architecture so as to expedite the architecture's emergence and the realization of the associated benefits.

The committee recognizes that one of the challenges to management in transition to a modern technical information architecture is existing "legacy" systems that do not conform to this architecture. The approach of upgrading legacy systems by replacing their functions with standard, reusable, new-technology building block components and developing interworking capabilities between legacy systems and modern open systems was discussed in Chapter 3 under Leveraging Legacy Investments and Fostering Rapid Acceptance of Information Technology. Alternative number three, discussed there, is particularly relevant to the Army because it addresses a situation where there is a large number of legacy systems.

The goal is to open up interfaces to the legacy systems that, over time, make data contained in these systems accessible to all systems and applications and that allow existing system-specific user interfaces to be replaced with modern graphical user interfaces (and other modern user interfaces) that access multiple systems and applications in an intuitive, user-friendly way. The interfaces will also allow the processing functionality within legacy systems to be replaced, over time, with building block processing functionality that conforms to the technical architecture.

While the transition of the large base of legacy systems will be a major undertaking, the committee believes that the sooner a technical architecture is developed, adopted, and enforced, the less costly and difficult this transition will be.

By replacing existing user interfaces with modern graphical user interfaces, the Army can make its systems more intuitive to use. This in turn should facilitate training, improve operator performance, and reduce the layers of people necessary in the processing chain. By replacing existing, incompatible communications interfaces, the Army will make it possible to communicate between systems without the reentry of data or the relaying of messages by human operators, thus reducing decision cycle times and reducing the numbers of people in the communication chain. By making legacy system data accessible via open interfaces, the Army will ultimately improve the ability of its commanders and individual soldiers to access the information they need for multiple applications.

RELATIONSHIPS WITH COMMERCIAL ORGANIZATIONS

For the Army to anticipate emerging technologies in the commercial sector, to learn from commercial successes and failures, and to be effective as a hunter-gatherer of technologies, it must build strong relationships with leading commercial information-technology R&D organizations. Relationships should include organizations that endeavor to create underlying or enabling technologies as well as those organizations on the leading edge of application of technologies in systems and end-user products. It is also essential that the Army's special needs be made known to commercial R&D firms so that these needs can influence the development of COTS technology. These strong ties can be forged in a number of ways.

For those technologies discussed in Chapter 4 where the committee recommended that the Army adopt commercial technologies, the Army should carefully track commercial trends in order to incorporate these evolving commercial technologies to keep Army systems and applications at the forefront of what commercial technologies make possible. For those technologies in Chapter 4 where the committee recommended that the Army adapt commercial technologies and attempt to influence commercial technology trends, the Army should focus on articulating its special needs, participating in the standards activities, and funding dual-use R&D activities. If necessary, it should fund Army-specific R&D to implement the needed adaptations. By committing a substantial amount of its resources to participating in and accessing commercial R&D activities, the Army will be far less likely to find itself conducting isolated R&D activities that duplicate larger and more effective commercial efforts yet fail to incorporate the latest enabling commercial advances.

The Army should maintain a strong internal and sponsored R&D effort focused on unique Army applications and the identification of Army needs, and the Army should actively articulate these needs to the commercial R&D community. The Army should participate in external R&D activities in carefully selected areas in order to influence technology trends and to obtain access to proprietary emerging commercial technology under appropriate nondisclosure agreements.

In working with commercial companies, the Army can return real value to the commercial companies by providing something that the companies have always had trouble obtaining, namely, solid end-user requirements. Commercial technology suppliers often must gamble simultaneously on new technologies and new-market creation with only limited understanding of the real needs of the customers they hope to serve with their new products. This has resulted in many technical successes and market failures. By becoming an applications test-bed, the Army can help reduce this commercial risk at the same time that it steers commercial development to meet its needs.

From actual warfighter experience and quick-turn-around experiments (such as those at III Corps), the Army can generate end-user requirements to which the commercial technology suppliers can build systems and equipment with increased confidence. The committee's work underlying this report has shown that virtually every system feature, attribute, or capability that commercial technology suppliers would build (ostensibly) to suit the Army would also have a counterpart for some class of commercial customer. Although the Army's needs do not cover every building block technology, they cover most of them. In particular, the Army has leading-edge needs for near-real-time intergrated information handling.

Therefore, the committee recommends that the Army proactively adopt the behavior of a "pseudo-commercial" customer with concrete, experience-based needs, ready to experiment with commercial technology suppliers in the development and beta testing of new multimedia information systems and equipment.

Additionally, the Army should encourage its R&D staff to spend a substantial amount of time and effort on understanding the latest R&D trends in industry (e.g., rotational assignments at commercial firms should be encouraged). Likewise, the Army should encourage commercial firms to place individuals with knowledge of the latest commercial trends in rotational assignments in Army R&D centers. The Army should increase its efforts to attract experienced R&D managers from commercial firms to participate in Army R&D management and high-level decision-making processes.

RESPOND TO THE NEED FOR REINVENTION

As discussed in Chapter 5 of this report, commercial experience indicates that radical organizational and institutional changes are needed to leverage information technology to its fullest potential. Therefore, the Army should expect that the rapid advances in communications and computational capabilities resulting from trends in commercial multimedia technologies will result in more than quantitative improvement in the ability of soldiers and commanders to execute existing command and control paradigms. It is likely that the Army will have to reinvent its doctrines related to command and control to take into account the entirely new paradigms that these capabilities will enable.

For example, the ability of commanders to directly access information that has been automatically filtered and processed into a form that is useful to them can enable the elimination of layers in the command and control hierarchy, just as information technologies have enabled the elimination of middle management layers in industry. This can result in much more rapid decision making, leading to the ability to execute much more rapid responses to the unfolding battlefield.

While the provision of wireless communication devices to individual soldiers at the squad level may have been too expensive in the past and may have resulted in unmanageable levels of communication, modern lowcost integrated circuitry has transformed wireless twoway communications devices into common consumer appliances. Coupled with modern information filtering and network management technologies it is possible that every soldier will have access to and be accessible via the battlefield information networks of the future.

ADOPT A SPIRAL MODEL; EMPHASIZE SIMULATION, MODELING, AND EXPERIMENTATION

The Army must adopt a spiral model of development where the iterative specification of requirements, prototyping, testing by users, and refinement/respecification of requirements proceeds in periods measured *in months* to create new systems and applications (as described in Chapter 3, in the subsection Adopting a Spiral Model). To achieve the desired iteration speeds, realistic prototyping, and the desired user feedback, this process must make heavy use of simulation, modeling, and experimentation.

In January 1993, a Defense Science Board panel reported that "[w]e believe that Advanced Distributed Simulation technology is here today, and that this technology can provide the means to improve training and readiness substantially, to create an environment for operational and technical innovation for revolutionary improvements, and to transform the acquisition process from within" (Defense Science Board, 1993). A key to fulfilling this vision lies in bringing concept developers together with users and engineers. This collaboration should take place early in the development process on a common virtual battlefield where they can visualize and discuss the merits of various designs and implementation approaches. Under this process, the effects of alternative design decisions can be easily visualized and their effects on key performance parameters identified.

One of the principal questions that must be addressed in the acquisition of any system is whether to adapt, modify, and combine existing off-the-shelf components or to initiate a substantially new system design effort. Such questions inevitably turn out to be multidimensional, involving many tradeoffs and requiring many supporting analyses. These are exactly the kinds of questions for which common experiences on a virtual battlefield by developers and users are most valuable. Users are able to envision the proposed system much more concretely and to anticipate problems in its use. Developers can observe the way users interact with the system and will frequently gain insights that would not otherwise become apparent until much later (and many dollars later) in the acquisition process.

It is important to bear in mind that the introduction of a new capability onto the battlefield rarely leaves other functions unchanged. Modeling and simulation can help explore the changes that could be introduced by the tactical employment of a proposed system. As discussed in Chapter 5, evaluators must be especially alert for changes in tactics that could be permitted or enabled by the new system and for adaptive changes in tactics by the opposing forces. In some cases, these countertactics may nullify many of the envisioned advantages of the proposed system. In addition, modeling and simulation can be used to explore other issues, such as training new units to use the system and the implications of the logistics loads that the proposed system would place on the combat service support infrastructure.

In many cases, detailed models of the system are not needed to support these analyses. Especially in the initial phases of concept evaluation, a system can be described in terms of performance probabilities, approximate representations of the physics involved, and a rough representation of the physics involved, and a rough representation of the user interface. If initial results appear promising, the richness of the simulation and user interface can be incrementally improved to support more detailed tests. Later, in the demonstration and validation and engineering development phases, more elaborate models and simulations may be used to focus on specific detailed design issues and tradeoffs.

Information systems can be particularly challenging because performance is difficult to quantify and validate. Through distributed simulation, human interface behavior and performance can be evaluated with live players. There is also a significant potential payoff in that software developed to simulate information systems can closely approximate the look and feel of the proposed systems. It is very likely that the software components developed for the systems simulation, particularly in the area of displays and interfaces, can be incorporated into actual systems.

An important area that should receive continuing, and perhaps increased, emphasis is research on human perception and performance in highly complex, temporally sensitive, information rich environments. Although a great deal of work has been undertaken, and is under way in understanding how to present complex multimedia information to users in commercial applications ranging from entertainment to medicine, the committee believes that much more remains to be done to understand how to facilitate and optimize the flow of multimedia information to commanders and between commanders and their subordinates in battlefield applications.

Experiments, such as those being conducted as part of the Louisiana Maneuvers, are critical for evaluating and iteratively improving new applications, systems, and subsystems that employ multimedia information technologies. Such experiments or exercises serve to determine operational deficiencies and to uncover new doctrine to reinvent the battlefield. The Army will have to continue to invest heavily in large-scale experimentation in order to optimize the application of commercial technology, make necessary modifications to meet military requirements, and to test and evaluate military-unique technologies that are needed to meet Army operational requirements.

MEASURING PROGRESS

Organizations make better progress toward a goal when they have a way of keeping score on how well they are doing. When the goal is a qualitative one, hard numbers are usually not appropriate. Borrowing a practice from the software industry, as discussed in the last subsection of Chapter 3 (Process Improvement), the committee recommends that the Army create and adopt a qualitative "index," like the sample shown on the following page, to show the series of steps it expects to pass through on its way to becoming a "Level 4" user of commercial technologies. Based on commercial experience with that process, the Army should expect that progression through these levels is a long-term proposition in which none of the levels can be skipped.

The committee recognizes that the Army needs to define its own goals and levels of achievement in this area. But such a qualitative index could (a) point toward a desired goal, (b) show what the Army considers to be progress toward the goal, and (c) provide a means of "keeping score" on progress.

OTHER RECOMMENDATIONS

The committee offers the following additional recommendations based on its intuitive reaction to some of the presentations it heard and the trips it made during the course of this study.

Putting Low-Cost Multimedia and Wireless Appliances Into the Hands of Squad-Level Soldiers

The committee believes that the ongoing and accelerating appearance of low-cost consumer appliances that employ multimedia information technologies (e.g., wireless personal communications devices, pagers, facsimile machines, portable personal computers, global-positioning-system appliances) will stimulate the ad hoc introduction of these appliances into Army applications by commanders and soldiers. The committee believes that this insertion of technologies is inevitable, and in most cases it is preferable to the alternative of not making use of the best commercially available technology in the battlefield. The committee recommends that the Army get ahead of this trend by accelerating the deployment of such low-cost COTS appliances in a standard way to avoid the proliferation of incompatible systems.

ARMY COMMERCIAL TECHNOLOGY AND PRACTICES INDEX

Level 1

- Only limited, ad hoc uses of commercial technology.
- Little or no joint experimentation with commercial companies.
- Lack of encouragement from traditional Army technology procurement organizations and personnel.
- No explicit budget available for exploiting commercial technologies.

Level 2

- Localized but intense experimentation with commercial technologies.
- Encouragement and protected environment provided by farsighted senior officers.
- Limited budgets made available by senior officers for experimentation.
- Experimental, cooperative initiatives with traditional military procurement organizations.
- Ad hoc cooperative experimentation with commercial companies.

Level 3

- Widespread commercial technology experimentation encouraged by senior officers and under way in multiple Army organizations.
- Experimentation accepted as a legitimate quick turnaround "front end" to traditional procurement practices.
- Elementary but standardized procedures and practices for cooperation with commercial companies established.
- Establishment and implementation of a technical architecture that facilitates and promotes the insertion of evolving COTS technology.
- Budgeting for commercial codevelopment.
- Measurable gains in Army performance produced by multimedia technologies.

Level 4

- All of Level 3, plus established and proven short-cycle-time procedures for working directly with commercial companies in front-end-activities.
- Established and usable technical architecture that is followed in new system procurements and legacy system upgrades.
- Active participation in the process by revitalized procurement organizations.
- Services and equipment spawned from Army cooperation commercially successful in health care, education and training, transaction processing, law enforcement, personnel administration, and supply management.
- Widespread reuse of building block technologies and greatly facilitated interoperability and ease of use within and among systems and applications.
- Reinvention of Army processes and organizations based on multimedia technologies.

The committee believes that low-cost (several hundred dollar) wireless communications appliances could be made available by the Army to squad leaders and individual soldiers for use in battlefield applications. These "radios" need not be highly "ruggedized," and could be viewed as throwaway items. Concerns with respect to security and detection could be addressed with minor modifications of COTS technology. For example, simple security codes could be required for activation. The use of low power, code division multiple access (CDMA), one of the technologies being deployed for emerging commercial personal communications systems, would make these wireless transmitting appliances resistant to detection, just as frequency-hopping spread spectrum does in today's military radios. These radios could be designed to communicate with nearby jeeps, tanks, or other armored vehicles which would act as base stations and would translate their signals into formats used for longer distance communications on the battlefield. In addition, these base stations could be used to filter information flows and manage communications to avoid traffic or information overload.

Encouraging Innovation

The committee observed the rapid insertion of innovative new technologies at III Corps at Fort Hood. These technologies were being evaluated using the spiral model of development described above. The committee would like to recommend to the Army that the innovative, rapid insertion and evaluation of technology observed at Fort Hood be used as a role model for the Army as a whole and be institutionalized as the "path forward" into the twenty-first century. This is the kind of activity that is representative of Level 2 of the recommended qualitative index discussed earlier.

SUMMARY

This chapter has described a technology management strategy by which the Army can successfully leverage multimedia information technologies for battlefield applications. The strategy includes the following recommendations:

- The Army should be a hunter-gatherer of technologies, seeking out and acquiring the best technologies wherever it can find them to meet overall strategic objectives and applying them in an opportunistic manner to meet battlefield demands.
- The Army should take advantage of the distinction between those technologies that are emerging and evolving in the commercial marketplace and will be available to everyone and those technologies that the Army can reasonably expect to create as competitive enablers to differentiate the Army from its adversaries.
- The Army must achieve a better balance in its procurement processes between keeping the processes fair and competitive and effectively acquiring and deploying information technologies with extremely short life cycles.
- The Army should create and enforce a technical architecture that (a) promotes reuse of building block technologies across multiple systems, interoperability between systems, and expedited insertion of new technologies to achieve cost reductions and performance improvements; and (b) facilitates ad hoc modifications of systems and applications to meet short-term needs in crisis situations.
- The Army should be an active participant in technology development in the commercial sector.
- The Army should respond to the need for reinvention. It should expect a requirement to reinvent its doctrines related to command and control to leverage the rapidly evolving technologies and to remain competitive with its adversaries.
- The Army must adopt a spiral model with a strong emphasis on simulation, modeling, and experimentation.
- The Army should create and adopt an appropriate qualitative index for uses in measuring progress made toward achieving its technology management goals.

In addition to recommendations on a sound technology management strategy, the committee also offered recommendations based on intuitive reaction to some of the presentations it heard and site visits it made during the course of this study. The committee recommended that the Army encourage innovation and be proactive in putting technologies into the hands of soldiers.

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Conclusions and Recommendations

This chapter summarizes the major conclusions and recommendations that appeared in the preceding chapters.

CONCLUSIONS

From the many expressions of Army requirements for future command, control, communications, and intelligence, the committee distilled six important Army needs for operational capabilities. These capabilities are necessary in order to realize those aspects of the vision of the Army of the future that are related to information acquisition, movement, management, and access. These needs are (1) improved situational awareness, (2) common relevant picture of the battlefield, (3) command on-the-move, (4) improved target handoff, (5) battle space expansion, and (6) information protection. A seventh need, to exploit modeling and simulation, was also considered because of its general importance to the Army and relevance to this study.

To help the Army satisfy its needs, there is a set of commercial multimedia building block technologies that collectively support a broad range of generic applications. Trends associated with these technologies (mostly qualitative, but also quantitative) indicate that a substantial level of research and development effort by companies will be put into these technologies over the next decade. This level of effort driven by commercial applications is likely to exceed greatly the amount of research and development effort that can be afforded by the Army. Thus, commercial requirements rather than Army needs are the principal determinants of the future directions taken by these technologies.

The committee defined a generic multimedia architecture that is useful for putting the building block technologies in perspective. This architecture has, from bottom to top, five layers. A sixth layer involving management and security cuts across the other five. The Army's needs tend to align most strongly with commercial needs in the middle layers (II to IV). The Army's unique needs tend to lie in Layers I and V, with some special requirements and concerns in Layer VI.

The committee related each of the Army's functional requirements in Chapter 2 to technology building blocks identified in Chapter 3. For each building block technology, the committee provided recommendations as to whether the Army should adopt commercial technology (C), adapt (modify) commercial technology (M), or develop Army-specific technologies (A) to meet its needs. The rationale for making these recommendations was also provided.

There are several ways in which advanced multimedia technologies might be employed in the first decade of the next century to support the Army of the future at the corps level and below. These were illustrated in a scenario depicting battle command in the twenty-first century.

The committee's analysis of the prognosis for the realization of the battlefield capabilities contained in the operational scenario considered the use of both commercial off-the-shelf technologies and technologies that might be created by Army-specific research and development investments. For the most part, however, the future capabilities will be determined by trends in commercial technologies.

In addition, the committee identified some important projections regarding the broader implications of the application of multimedia technologies at the corps-level and below; these implications go beyond mere improvements in the ability to acquire, process, and communicate information. Specifically, the committee forecasts changes in organization, doctrine, and tactics as well as the need to actively experiment and to iteratively design and develop.

The committee developed a technology management strategy for the Army. The recommendations that follow constitute the key elements for this strategy.

RECOMMENDATIONS

Based on its understanding of Army plans and needs related to the battlefield and the current capabilities and future trends in commercial-off-the-shelf multimedia information technologies, the committee makes the following recommendations. The committee acknowledges that some of the recommendations have been made before, but it wishes to reiterate them to add weight to these recommendations in the hope of accelerating their implementation and to add specific support for them in the context of applications of multimedia information technologies. In particular, the committee believes that these recommendations are specifically relevant to multimedia information technologies and applications because of the very short time scales within which these technologies evolve and because of the widespread application of these technologies in commercial domains.

Recommendation 1: The Army should be a hunter-gatherer of technologies, seeking out and acquiring the best technologies wherever it can find them, to meet its overall strategic objectives, and applying them in an opportunistic manner to meet the demands of the battlefield. The Army should leverage commercial-off-the-shelf technology (i.e., design applications and systems that can utilize such technology rather than setting objectives and requirements that require the invention of nonexistent technology). The Army should not compete with the commercial sector in developing generically applicable technology.

Recommendation 2: The Army should carefully distinguish between (a) those technologies that are emerging and evolving in the commercial marketplace and will be available to everyone, including the Army's adversaries, and (b) those technologies that the Army can reasonably expect to create as competitive enablers to differentiate the Army from its adversaries. For those technologies that fall in the former category, the Army should focus on expediting and experimenting with their innovative use in battlefield applications as a means of producing competitive advantage. For those technologies that fall into the latter category, the Army should invest in Army-proprietary research and development efforts to achieve the desired differentiating advantages. The committee has provided specific recommendations in Chapter 4 of this report regarding which multimedia information technologies fall into the former category, the latter category, or a combination of both. These recommendations were summarized in Table 4-4.

Recommendation 3: The Army must achieve a better balance in its procurement processes between the imperative to make these processes fair and competitive and the imperative to effectively acquire, insert, and deploy information technologies whose life cycles can be as low as 18 months. Specifically, the Army must recognize the iterative interaction between requirements and what is technically feasible. Setting rigid requirements for systems years in advance of their likely deployment will result in the deployment of obsolete technologies with their associated cost and performance penalties, lost opportunities to deploy capabilities that were not anticipated or not believed to be feasible at the time requirements were set, and wasted efforts in the development of technologies that duplicate those that become commercially available at lower costs and have better performance.

Recommendation 4: The Army should create and enforce a technical architecture that (a) promotes the reuse of building block technologies across multiple systems, interoperability between systems, and expedited insertion of new technologies to achieve cost reductions and performance improvements, and (b) facilitates ad hoc modifications of applications and capabilities to meet short-term needs in crisis situations. The Army must provide incentives to program managers and contractors to make the short-term investments needed to implement systems and building blocks that are compliant with the architecture in order to realize the long-term benefits articulated above.

Recommendation 5: The Army should be an active participant in technology development in the commercial sector. The Army should access information regarding commercial technology trends, influence commercial technology trends to accommodate Army-specific requirements, and proactively endeavor to benefit from commercial experiences and innovations in the application of technology.

Recommendation 6: The Army should respond to the need for reinvention. It should expect that rapid advances in communications and computational capabilities resulting from trends in commercial multimedia technologies will result in more than quantitative improvement in the ability of soldiers and commanders to execute existing command and control paradigms. It is likely that the Army will have to reinvent its organizations, doctrines, and tactics related to command and control to leverage these rapidly evolving technologies and to remain competitive with its adversaries.

Recommendation 7: The Army must adopt a spiral model of development where the iterative specification of requirements, prototyping, testing by users, and refinement/respecification of requirements proceeds in periods measured *in months* to create new systems and applications. This process must make heavy use of simulation, modeling, and experimentation in order to achieve the desired iteration speeds and to achieve realistic prototyping and desired user feedback.

Recommendation 8: The Army should create and adopt an appropriate qualitative index as a means to measure progress made toward achieving its technology management goals.

Appendix

Meetings and Activities

FULL COMMITTEE MEETINGS

1. September 28–30, 1994 Fort Gordon, Augusta, Georgia

Objective: Gain understanding of Army command, control, communications, and intelligence requirements.
Presentations:

(a) "Louisiana Maneuvers," Brig. Gen. David Ohle, Louisiana Manuevers Task Force.
(b) "Digitization," Col. Christopher Fornecker, Army Digitization Office.
(c) "Dismounted Battle Space Battle Lab," Mr. Grady Scott, Dismounted Battle Space Battle Lab.
(d) "Combat Development," Col. Robert Forrester, U.S. Army Signal Center.
(e) "Where the Rubber Meets the Road," Lt. Col. John Collier, U.S. Army Combined Arms Center and Fort Leavenworth.
(f) "Army C^3I Requirements," Col. Patrick Lamar, U.S. Army Combined Arms Center and Fort Leavenworth.
(g) "U.S. Army Information Systems for Command, Control, Communications, and Computers," Lt. Col. William Burse, Enterprise Task Force, Directrate of Information Systems for Command, Control, Communications, and Computers, Department of the Army.
(h) "Views of Deputy Chief of Staff for Operations and Plans," Col. Ancil Hicks, Office of the Deputy Chief of Staff for Operations and Plans, Department of the Army.
(i) "Army Science Board Views," Dr. William Neal, The MITRE Corporation.
(j) "Battle Command Battle Lab," Mr. Tom Mims, Battle Command Battle Lab.
(k) "Real-Life Problems," Col. Patrick Lamar, U.S. Army Combined Arms Center and Fort Leavenworth.
(l) "Charge to the Panels," Dr. Stewart Personick (Chairman), Committee on Future Technologies for Army Multimedia Communications.

2. October 25–26, 1994 Washington, D.C.

Objective: Broad exposure to commercial multimedia technologies and reinventions and discussion of their applications to Army needs.
Presentations:

(a) "Broadband Wireless Communications for Battlefield Applications," Dr. Bruce Fette, Motorola.
(b) "Data Mining," Mr. Robert Steele, Open Source Solutions, Inc.
(c) "Reinvention in Industry/Institutions," Dr. Dan Schutzer, Citibank.
(d) "Compression of Video and Images," Mr. Charles Crawford, Compression Labs, Inc.
(e) "Speech Technology," Mr. Richard Schwartz, Bolt Berenak & Newman.
(f) "Intelligent Transportation Systems," Dr. Arthur Salwin, The MITRE Corporation.
(g) "Presentation and Discussion on Evolution of TCP/IP Protocol to Support Multimedia and Real-Time Applications," Ms. Allison Mankin, Kaman Sciences Corporation at the Naval Research Laboratory.
(h) "Communication Requirements for the Future," Mr. Andrew Marshall, Department of Defense.
(i) "Asynchronous Transfer Mode Over Wireless Networks," Mr. Nelson Sollenberger, Bell Communications Research, Inc.

(j) "Secure Systems-Making and Keeping Them Secure," Dr. Ernest Brickell, Sandia National Laboratories.
(k) "ATM," Dr. G. Ray Ritchie, Bell Communications Research, Inc.
(l) "Battery Technology," Dr. Frough Shokoohi, Bell Communications Research, Inc.

3. January 24–25, 1995 Washington, D.C.

Objective: Working meeting to review status of Chapters 3, 4, and 5 and ensure consistency with statement of task.
Presentations:

(a) "Army C^3I Technologies," Mr. Robert Giordano, U.S. Army Communications and Electronics Command.
(b) "Mobile and Wireless Information Systems," Dr. Barry Leiner, Universities Space Research Association.

4. June 6, 1995 Washington, D.C.

Objective: Review and sign-off concurrence draft of the committee report.

OTHER MEETINGS

1. Planning Meeting, January 4, 1995 Washington, D.C.

Objective: To gather facts for the committee by meeting with General Gordon R. Sullivan, Chief of Staff, U.S. Army. Attended by S. Personick (Chairman), A. McLaughlin, J. Smith, L. Streeter, L. Wishart.

2. Site Visit, January 30, 1995 Fort Belvoir, Virginia

Objective: To observe Joint Precision Strike Surface-to-Surface demonstration.
Attended by S. Personick (Chairman), A. McLaughlin.

3. Site Visit, March 20–21, 1995 Fort Hood, Texas

Objective: To observe III Corps soldiers and vehicles, view simulation facilities, visit the III Corps battle lab, and dialogue with persons who are currently addressing issues relating to future technologies and requirements.
Attended by S. Personick (Chairman), D. Leeper, C. Manders, B. McCune, A. McLaughlin, L. Wishart.