A Guidebook for Nighttime Construction: Impacts on Safety, Quality, and Productivity

DETAILS

122 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-25847-0 | DOI 10.17226/22723

AUTHORS

Shane, Jennifer S.; Kandil, Amr; and Schexnayder, Clifford J.

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 726

A Guidebook for Nighttime Construction: Impacts on Safety, Quality, and Productivity

Jennifer S. Shane
IOWA STATE UNIVERSITY/INSTITUTE FOR TRANSPORTATION
Ames, IA

Amr Kandil
PURDUE UNIVERSITY
West Lafayette, IN

Clifford J. Schexnayder
ARIZONA STATE UNIVERSITY
Tempe, AZ

Subscriber Categories
Highways • Materials • Design

Research sponsored by the American Association of State Highway and Transportation Officials
in cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2012
www.TRB.org

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Academies was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP REPORT 726

Project 10-78
ISSN 0077-5614
ISBN 978-0-309-25847-0
Library of Congress Control Number 2012944315

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet at:

http://www.national-academies.org/trb/bookstore

Printed in the United States of America

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, on its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is one of six major divisions of the National Research Council. The mission of the Transportation Research Board is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied activities annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. **www.TRB.org**

www.national-academies.org

C O O P E R A T I V E   R E S E A R C H   P R O G R A M S

AUTHOR ACKNOWLEDGMENTS

The authors wish to thank personnel with the following agencies who responded to our calls for information. This Guidebook would not have been possible without the input and assistance of these individuals: Alabama Department of Transportation, Alberta Transportation, Arizona Department of Transportation, Colorado Department of Transportation, Connecticut Department of Transportation, Delaware Department of Transportation, Federal Highway Administration, Georgia Department of Transportation, Illinois Department of Transportation, Iowa Department of Transportation - Office of Construction, Kansas Department of Transportation, Kentucky Transportation Cabinet, Louisiana Department of Transportation, Maine Department of Transportation, Manitoba Infrastructure and Transportation, Maryland State Highway Administration, Massachusetts Highway Department, Michigan Department of Transportation, Minnesota Department of Transportation, Missouri Department of Transportation, Nebraska Department of Roads, Nevada Department of Transportation, New Jersey Department of Transportation, New York State Department of Transportation, North Carolina Department of Transportation, Oklahoma Department of Transportation, Oregon Department of Transportation, Pennsylvania Turnpike Commission, Saskatchewan Ministry of Highways and Infrastructure, South Carolina Department of Transportation, Texas Department of Transportation, Utah Department of Transportation, Vermont Department of Transportation, Virginia Department of Transportation, Washington State Department of Transportation, Wisconsin Department of Transportation, and Wyoming Department of Transportation.

FOREWORD

By David Reynaud
Staff Officer
Transportation Research Board

NCHRP Report 726 provides a Guidebook of nighttime construction best practices concerning 1) implementation of new or innovative ideas to convert necessary work activities to effective nighttime production; 2) proven safety processes; 3) development of communication strategies (both external and internal); and 4) work-zone illumination methods, including a list of new and innovative lighting equipment with associated advantages and disadvantages. Also listed are activities that may increase or decrease productivity when performed during the nighttime period, as well as methods for conducting work-zone risk analysis planning and implementation for different types of work. This information is presented as a hands-on, user-friendly resource with hard-to-miss color icons that indicate key (not-to-forget) information, tips for proper use of the information, and additional sources of useful information. This Guidebook will be of interest to contractor and transportation agency personnel involved in night work, both in planning and in on-site activities.

Increasing daytime traffic volumes, rush-hour restrictions on necessary lane and road closures, and increased cost due to abbreviated daytime construction worker shifts are causing transportation agencies to increasingly rely on night work. Nightshift road construction has always evoked the perception of poor quality product, low production rates and longer project duration, increased safety issues for both workers and travelers, and negative environmental impacts on nearby residences and businesses.

Under NCHRP Project 10-78, a research team led by Iowa State University has developed comprehensive guidelines for the conduct of nighttime highway construction and maintenance operations. These guidelines are based on best practices and strategies for nighttime operations that address the safety of both contractor's and owner's personnel, the safety of the traveling public, the quality of the as-built facility, productivity, risk, and construction nuisances to both neighbors and workers.

To achieve project objectives, the researchers conducted a literature search of the latest studies on the impact of nighttime construction operations on safety, quality, environmental factors, and productivity. In addition, the researchers have collected information by polling 37 highway agencies and other knowledgeable stakeholders to identify the project circumstances and types of work that are potentially appropriate for nighttime conduct, to identify the advantages and disadvantages of nightshift work, to point out the appropriate measures used to mitigate construction nuisances associated with nighttime work activities, and to evaluate the successes and failures of past nighttime operations for lessons learned.

CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

SUMMARY

A Guidebook for Nighttime Construction: Impacts on Safety, Quality, and Productivity

Roadways in the United States are becoming more congested each day. These same roads are also often reaching the middle or end of their useful lives. Transportation agencies are working diligently to meet the demands of the traveling public through construction and maintenance activities.

Because of increased traffic congestion during the day, road construction and maintenance activities are being conducted during nighttime hours. Concern over the impact of nighttime activities on risk, illumination, nuisances, productivity, quality, cost, safety, and communications, as compared to daytime activities, has inhibited the use of nighttime construction by some agencies. The concerns have prompted research to investigate the impacts of nighttime construction projects and the development of a research report and this practice-oriented Guidebook.

Through a multi-method approach of literature review, surveys, case studies (with semi-structured interviews), and field data collection, the discrepancies between nighttime and daytime activities were found to be minimal. With early identification of issues and good planning—beginning early in project development—the advantages of nighttime construction can outweigh the difficulties and yield a successful project. The conclusions that were reached include the following:

- Successful nighttime construction requires good illumination.
- The decision to use nighttime construction should be made as early in the project development process as possible.
- Nighttime construction concerns are not mutually exclusive, as there is interaction between them. (For example, nighttime construction requires added cost for illumination and better traffic control, but productivity is usually better. Therefore, overall project cost is comparable to cost for a daytime project.)
- Early decision making and proper planning can limit the disadvantages of nighttime work and enhance the advantages.

CHAPTER 1

Introduction and Framework

Traffic congestion, especially in metropolitan areas, places a significant and serious burden on the public and threatens the economic vitality of the nation. A significant portion of traffic congestion is attributable to roadway construction and maintenance activities (10 to 24 percent as reported in various studies).

One way to reduce the congestion effects of roadwork activities is to perform such activities during times of reduced traffic demand. Traffic demand fluctuates dramatically over a 24-hour period; the percentage of daily traffic each hour of the day is much less during the evening and early morning hours than it is during the daytime.

Data taken during the summer of 2001 suggest that one-third of the work zones present on national highway system roadways were active primarily at night, compared to 58 percent of the work zones that were active during the day (and nine percent of the projects involved continuous work activities over both daytime and nighttime hours) (Ullman et al. 2004).

The Problem

Although the benefits to performing work activities at night are obvious and significant, particularly on high-volume roadways in urban areas, a number of issues can make night work challenging.

Safety of Personnel

According to some sources, night work presents challenges to work-crew safety. For example, night work generally involves degraded vision for the workers because of lower overall luminance levels in the work zone, the effects of shadows created by equipment and materials, and glare from vehicle headlights and equipment lights around the work area. In addition, concerns exist over potential degradations in worker attention levels and overall health due to the disruption of the body's natural circadian rhythms. Finally, questions have arisen as to the effect of performing work at night, specifically as it affects worker quality of life as a result of reduced social- and family-interaction opportunities.

Safety of the Traveling Public

The nighttime work-zone issues related to the driving public that are most commonly cited include the following:

- Reduced visibility for drivers due to lower levels of light at night (this is especially an issue for older drivers with vision deterioration).

- Decreased driver expectancy for encountering road work activities at night.
- Higher percentage of impaired and/or drowsy drivers on the road at night.
- Higher traffic speeds approaching and traveling through the work area (potentially leading to more severe crashes).

Quality of Work and Production

Working at night can have implications on work quality, production rates, and costs for the contractor. These implications may translate into higher project costs for the agency. The effects of lower light levels on worker vision may reduce work quality, and night work can require a cost premium for materials and labor. However, lower traffic volumes make it easier for materials to be delivered to or transported from the jobsite, potentially increasing productivity and reducing overall costs.

Construction Nuisances

Night work can have impacts on adjacent neighborhoods and businesses that would either not be experienced or not be as disturbing if they occurred during the daytime. These impacts include noise levels that affect sleep patterns of nearby residents, glare from temporary lighting systems that intrude upon residential dwellings, and accessibility to businesses that operate primarily at night.

The hazards, demands, and nuisances have been the subject of a number of previous research studies:

- Illumination requirements of nighttime work zones (El-Rayes and Hyari 2005a, El-Rayes and Hyari 2005b, Hyari and El-Rayes 2006a, Hyari and El-Rayes 2006b, and Nassar 2008)
- Evaluation of construction nuisances during nighttime work zones (Schexnayder 1999 and Schexnayder and Ernzen 1999).
- Evaluation of the impact of nighttime work zones on driver and worker safety (Arditi et al. 2004 and Arditi et al. 2007).
- Quantification of the impact of nighttime operations on construction cost and quality (Al-Kaisy and Nassar 2005, Kumar and Ellis 1994, and Lee and Thomas 2007).

While previous studies made significant contributions to the advancement of the practice of nighttime construction, this Guidebook seeks to provide a comprehensive assembly of information concerning nighttime construction work in transportation corridors.

According to previous research, 27 state transportation agencies (STAs) reported that they have experienced serious nighttime construction issues (Schexnayder and Ernzen 1999). However, most agencies reported that with appropriate project specifications, a viable nighttime construction environment can be created.

Controlling specifications need to clearly indicate to the contractor the critical issues associated with a project and how to address them. A good construction specification is an effective tool in mitigating the effects of nighttime construction issues. The mechanisms to achieve that goal will vary from one contract to another because of area-specific conditions, the type of construction, the traffic flow that must be handled, the inherent nature of project neighbors, and the desires of the community.

Supplemental standard provisions can dictate specific measures on a contract-by-contract basis to address special local issues. The existence and importance of lighting and nuisance control specifications need to be emphasized at pre-bid and pre-construction conferences.

The Decision

The decision to conduct construction activities at night can be made at various levels of the STA and at various points in the project development process or even by a construction company, depending on the individual project. However, this decision needs to be made as early in the project development process as possible and communicated to all project participants throughout the remainder of project development and construction. This is to ensure that the decision is reflected in the project planning, design, and cost estimation.

The Project Development Process

Transportation projects typically go through five phases of project development (Anderson et al. 2007):

1. Planning.
2. Scoping.
3. Design.
4. Advertise and Bid.
5. Construction.

In different transportation agencies, the development phases may have different names; however, these are the typical activities. While Table 1.1 describes the design-bid-build method, the typical activities may vary depending on the project delivery method.

The Research Project

To help STAs and responsible personnel understand nighttime construction issues, the National Cooperative Highway Research Program (NCHRP) initiated the project that produced this Guidebook. The objective of this guide is to provide comprehensive and concise material to support nighttime highway construction and maintenance operations.

Table 1.1. Project development process (Anderson et al. 2007).

Development Phase	Typical Activities
Planning	Determine purpose and need, determine whether it is an improvement or requirement study, consider environmental factors, facilitate public involvement/participation, and consider interagency conditions.
Scoping	Conduct environmental analysis, conduct schematic development, hold public hearings, determine right-of-way impact, determine project economic feasibility, obtain funding authorization, develop right-of-way, obtain environmental clearance, determine design criteria and parameters, survey utility locations and drainage, make preliminary plans such as alternative utility locations and drainage, make preliminary plans such as alternative selections, assign geometry, and create bridge layouts.
Design	Acquire right-of-way; develop plans, specifications, and estimates; and finalize pavement and bridge design, traffic control plans, utility drawings, hydraulics studies/draining design, and cost estimates.
Advertise and Bid	Prepare contract documents, advertise for bid, hold a pre-bid conference, and receive and analyze bids.
Construction	Determine the lowest responsive bidder; initiate contract; mobilize; conduct inspecting and materials testing; administer contract; control traffic; and construct bridge, pavement, and drainage.

The material presented in this guide was assembled through a review of literature, surveys, interviews with agencies and contractors, and limited field measurements. Additional information on the project can be found in the contractor's final report.

The information for this project was collected from many different sources, but the primary sources were STA personnel. A national survey was conducted to collect preliminary information from each of the state highway agencies regarding each of the nighttime construction areas of interest. Later, more in-depth interviews were conducted to collect additional information and gather field observations. Information was also assembled from published sources. The culmination of information from all sources is presented in this Guidebook.

Guidebook Framework

This Guidebook provides a practice-oriented presentation of nighttime construction issues. The objective is to provide practitioners with a comprehensive reference on nighttime construction practices.

The information in this guide is provided in chapters specific to each of the considerations of nighttime construction. Some of the information and chapters are more specific for nighttime activities, while others are more general, primarily because practices may not be different between daytime and nighttime construction.

Chapter 1: Introduction and Framework

Chapter 1 provides readers with an understanding of the challenges faced in nighttime construction. This chapter also describes the development process for the Guidebook and its layout.

Chapter 2: Risk

Risks inherent to construction work zones are numerous. The obvious risks are related to safety and include vehicle intrusions in work zones, workers being struck by intruding vehicles, workers struck by construction equipment, and construction equipment intrusion in operational lanes. In addition, other risks in nighttime construction relate to quality, cost, communication, and nuisances. This chapter introduces these risks and includes a discussion on risk management. The remainder of the Guidebook chapters can then be used to address these risks.

Chapter 3: Illumination

Illumination is not often considered for daytime construction, while it is imperative to successful completion of a nighttime project. Therefore, illumination is a unique and critical factor in nighttime activities. This chapter presents lighting requirements for highway construction as well as potential lighting guidelines for different nighttime construction activities.

Chapter 4: Nuisances

Several types of control mechanisms exist for noise nuisances during highway construction. These mechanisms include source, path, and receptor controls. This chapter explores each type of control mechanism and discusses methods found for control of nighttime construction nuisances. The chapter also touches briefly on vibration and dust nuisances.

6 A Guidebook for Nighttime Construction: Impacts on Safety, Quality, and Productivity

Chapter 5: Productivity

The productivity levels of nighttime construction have not been researched in depth. This chapter presents ways to improve productivity, as well as potential pitfalls that may be encountered.

Chapter 6: Quality

The objective of a transportation agency is to provide a quality project. Quality is often one of the keys in contractor payment. Project quality is linked to the inspectability of the product being delivered. This chapter provides information for the visual requirements necessary to inspect different types of work properly, along with information from various agencies on quality efforts in nighttime construction.

Chapter 7: Cost

The chapter includes discussions about factors that have an impact on cost and guidance on what to consider when planning and budgeting nighttime construction activities.

Chapter 8: Safety

The safety of nighttime work has an impact on both the traveling public and the construction workers. This chapter examines the safety issues for both.

Chapter 9: Communications

Many complaints about nighttime construction nuisances can be mitigated through a good communications program. This chapter explores communication—both with the public and within the transportation agency—and presents practices from agencies across the country.

Chapter 10: Interactions

Chapter 10 of the Guidebook discusses the interactions that are inherent between the topics previously discussed. The factors considered in nighttime construction decisions and planning interact with each other, given that the risks associated with nighttime construction activities are not mitigated exclusively or monitored by only one method. For example, safety can be improved with illumination, but providing illumination can add cost to the project.

Chapter 11: Summary for Implementation and Keys to Success

The conclusions of the Guidebook offer a final overview perspective of the information provided on nighttime construction.

References

Source information for the citations in this Guidebook is provided in the references.

Acronyms and Abbreviations

A look-up table for acronyms and abbreviations used in this Guidebook is provided.

Table 1.2. Guidebook content.

Symbol	Section Name	Content
	**Key Take-Away**	• An indicator of key, not-to-forget information—for quick reference.
	**Tip**	• Possible tips for use of information.
	**Resources**	• Sources of useful information: ○ Internet. ○ Literature. ○ Agency or group. ○ Reports.

Appendix: Sample Safety Quiz

This appendix contains a sample toolbox talk, written quiz, and answer sheet on safety activity responsibilities.

Guidebook Content

Each chapter of the Guidebook generally has three sections: an introduction, body, and conclusion. Within the chapters, certain types of information are highlighted to call attention to important details. These include key take-aways, tips, and additional resources (Table 1.2).

How to Use the Guidebook

This Guidebook provides information on primary of areas of interest to consider and decisions to be made in planning and conducting nighttime construction and maintenance activities. The Guidebook is intended to act as an overall reference for this topic and explores each of the topical areas separately, and, in addition, looks at the interaction among the topic areas.

Considerations about nighttime work need to begin early in the planning or design development process. Therefore, the audience for this Guidebook spans all members of the project development and construction process within the STA. All users could benefit from reading the Introduction and Framework, Risk, and Summary for Implementation and Keys to Success chapters. Additional chapters of importance depend on the user's informational needs as outlined in Table 1.3.

Summary

Nighttime work on the nation's highways is becoming more prevalent for a number of reasons. At the same time, nighttime work presents a number of challenges.

The purpose of this Guidebook is to help individuals and teams who are planning or working on nighttime projects understand and address the challenges of working at night. With proper planning, STA teams can effectively address nighttime construction challenges during the project development process to ensure a successful project.

Table 1.3. Guidebook chapters of particular interest by user role.

User	Chapter	Justification
Planner	3. Illumination	Planning for illumination needs to begin during the earliest stages of project planning and development.
	8. Safety	Both worker and public safety are paramount to project success.
Cost Estimator	3. Illumination	Costs to light work areas need to be included in estimates.
	4. Nuisances	Nuisance mitigation needs to be included in estimates.
	5. Productivity	Working at night can increase or decrease productivity and have an impact on project estimates.
	6. Quality	Working at night can affect quality and may have an impact on pay items as well as incentive and disincentive amounts.
	7. Cost	Lighting costs are of particular interest in cost estimates.
Designer	3. Illumination	Early installation of permanent lighting can reduce the costs of temporary lighting.
	4. Nuisances	Nuisance mitigation needs considered during design.
	6. Quality	Establishing standard quality measures is important so that product quality does not differ for nighttime activities.
	8. Safety	Different design ideas may need to account for worker and public safety.
Project Manager or Field Engineer	3. Illumination	Permanent and temporary illumination considerations for the job site need to be monitored and corrected immediately beyond the project planning phase.
	4. Nuisances	A clear understanding of how to mitigate nuisances is required.
	7. Cost	Work at night may have an impact on construction costs.
	8. Safety	A safe project site for agency personnel, contractor personnel, and the traveling public is required.
	9. Communications	Effective communications within the project group and with the public helps ensure project success.
Construction Inspector	3. Illumination	Good illumination is required.
	4. Nuisances	Nuisance mitigation measures need to be monitored.
	5. Productivity	The project site needs to support productivity.
	6. Quality	The quality specification for the project must be met.
	8. Safety	Good safety practices are required.
	9. Communications	Effective communications, both on the jobsite and with the public, can be the key to a successful project.

Several of the topics covered in this Guidebook are specific to nighttime construction, such as illumination,whereas others include a discussion that is not all that different from the efforts needed on all projects regardless of the time of day, such as communications. While these discussions are more generic, project personnel are reminded that these roadway construction challenges are no less important and may have a greater impact during nighttime construction.

CHAPTER 2

Risk

Since the latter half of the 20th century and the beginning of the 21st century, urban traffic congestion has increased. The need for highway rehabilitation and maintenance work has further added to the traffic-congestion situation. Therefore, STAs are requiring that more projects be constructed during reduced traffic hours—including nights—as a means of reducing work-zone impacts on traffic flow.

Nighttime construction introduces numerous risks to a construction project. One clear set of examples is driver and worker fatigue and reduced visibility, which are factors that could increase safety risks. Night work, because of reduced visibility, creates a situation in which it is more likely to have vehicle intrusions into work zones and construction equipment intrusions into traffic lanes. In addition, the risk of driver error is higher at night. Both transportation officials and contractors find it crucial to understand and appreciate the severity and degree of nighttime work-zone impacts on both the public and the project workforce.

Other major factors contributing to the risks of nighttime work are human factors such as sleep, stress, work, social/domestic issues, and psychological characteristics, such as appetite and safety. Additional factors associated with the risks of nighttime construction work zones are reduced work space for machinery and equipment movement, inadequate lighting, high speed of traffic during the night, and long working hours (12 to 14 hours) (Holguin-Veras et al. 2001). Reports show that shift work in general can impair overall worker alertness, reaction times, and even motor skills (Ullman et al. 2006).

Many diverse strategies to mitigate risks need consideration when deciding to complete construction tasks at night, so the risk analysis process needs to begin in the early stages of project development. Decisions during project scoping and design, as well as in development of the traffic management plan, all affect jobsite risk. Numerous resources are available from the Federal Highway Administration (FHWA) and other transportation agencies to help organizations mitigate nighttime construction risks.

Different factors, such as quality and productivity, which can have an impact on nighttime construction activities, are presented throughout this Guidebook. Each factor can be seen as a risk topic and many different methods are available for addressing them as risks.

Risk Management Process

The best way to address nighttime construction work-zone risks and hazards is through risk management programs. It is suggested that agencies and contractors begin their risk management processes early and review the risk management program carefully prior to beginning nighttime work.

Key Take-Aways

- Accident rates for work zones with lane closures are 75 percent higher than those for work zones without lane closures (Cottrell 1999).
- Planning for safe night operations needs addresses both construction vehicles and traffic.

Risk management is the term used to describe a sequence of analysis and management activities focused on identifying and creating a response to risks and, in the case of nighttime construction, to project-specific risks. Various organizations use very similar steps, but slightly different terms, to describe their risk management approach. These are the important risk management steps:

1. Risk identification.
2. Risk assessment/analysis.
3. Risk mitigation and planning.
4. Risk allocation.
5. Risk monitoring and control.

Risk identification is the process of determining which risks might affect the project and documenting their characteristics using tools such as brainstorming and checklists.

Risk assessment/analysis involves the quantitative or qualitative analysis that assesses impact and probability of risk. *Risk mitigation and planning* involves analyzing risk response options (acceptance, avoidance, mitigation, or transference) and deciding how to approach and plan risk management activities.

Risk allocation involves placing responsibility for a risk on a specific party or parties—typically through a contract. The fundamental tenets of risk allocation include allocating risks to the party that is best able to manage them, allocating risks in alignment with project goals, and allocating risks to promote team alignment with customer-oriented performance goals.

Risk monitoring and control is the capture, analysis, and reporting of project performance, usually as compared to the risk management plan. Risk monitoring and control assists in tracking and resolution.

Key Take-Away

Risk assessment should begin early when making the decision to use nighttime construction.

Understanding that the risk management process is repetitive and cyclical is important. As the project evolves, some risks will be resolved or diminished, while others may surface and need to be addressed. The five fundamental risk management steps need to be applied throughout the project life cycle for a successful project. The extent of application of each step varies as the methods and tools used to support these steps depend on the project development phase and project complexity (Molenaar et al. 2010).

1. Risk Identification

Risk management is especially important with nighttime work. Risk management planning for nighttime construction should begin with identification of risks that may affect the work and the traveling public. Risk identification can be accomplished through peer reviews of project documentation, studies, reports, preliminary plans, estimates, and schedules and should produce a comprehensive checklist of possible risks.

The risk identification process begins with the team compiling a list of the project's possible risks. The identification process varies depending on the nature of the project, but most identification processes begin with an examination of issues and concerns created by the project development team.

Issues and concerns can be derived from an examination of the project description, work breakdown structure, cost estimate, design and construction schedule, procurement plan, or general risk checklists. Checklists and databases can be created for recurring risks, but project team experience and subjective analysis is usually required to identify project-specific risks (Molenaar et al. 2010).

Teams must be cautious not to overlook risks or focus on solving problems during the risk identification process. Engineers and project managers inherently have an optimistic bias when thinking about uncertain items or situations, because they are, by nature, problem solvers. During the identification stage, the focus is on numerating risks, not on mitigating them. Opportunities and solutions are addressed later during the mitigation process.

2. Risk Assessment/Analysis

Once risks are identified, teams can perform qualitative and quantitative risk analysis to assess the impact and likelihood of the identified risks. During qualitative risk analysis, identified risks are assessed for their probable occurrence and how they impact the work or the public.

That said, risk assessment has two aspects. The first determines the likelihood of a risk occurring (risk frequency) and classifies it along a continuum from very unlikely to very probable. The second aspect judges the impact of the risk should it occur (consequence severity).

Risks can affect projects in diverse ways. The effects of risks are usually apparent in project outcomes by increasing cost or schedule directly. However, some risks influence the project by affecting the public, public perception, the environment, or safety and health considerations.

Some of the qualitative risk assessment techniques include recording risk details and relationships and ranking risks relative to each other, while quantitative risk analysis helps assess, through numeric estimation, the probability of the nighttime activity meeting the project cost and schedule. Numeric estimation can be done with the use of Monte Carlo simulation, which is a quantitative tool for analyzing project risks and uncertainties, for example.

3. Risk Mitigation and Planning

The objectives of risk mitigation and planning are to explore risk response strategies for the high-risk items identified in the qualitative and/or quantitative risk analysis. The process identifies and assigns responsibility for each risk, ensuring that each significant risk has an owner.

The owner of the risk could be an agency planner, engineer, or construction manager. The owner might even be an insurance company, depending on the point in project development, or it could be a private-sector contractor or partner, depending on the contracting method and risk allocation.

Key Take-Away

Formalizing risk mitigation and planning throughout an agency establishes a risk culture that results in better cost management from planning through construction.

4. Risk Allocation

After the team identifies and analyzes the project risks, it is essential to determine the appropriate and most suitable actions for mitigation to reduce the threats that the risks impose on the nighttime work (i.e., through increased cost or increased safety measures). The process involves assigning responsibility to the various parties to implement the decided-upon mitigation strategies.

Finally, the contract is a risk allocation vehicle. By defining roles and responsibilities, the contract assigns risks. Risk allocation in any contract affects cost, time, quality, and the potential for disputes, delays, and claims.

Key Take-Away

Contractual misallocation of risk has been found to be a leading cause of construction disputes in the United States (Smith 1995).

5. Risk Monitoring and Control

Through the risk monitoring and control stage, the parties will continuously monitor the risks and, if possible, identify any potential new risks. The objectives of risk monitoring and control are as follows:

- Track the identified risks systematically.
- Identify any new risks.
- Manage the contingency reserve established for the project effectively.
- Capture lessons learned for future risk assessment and allocation efforts.

Risk monitoring and updating occurs after the risk mitigation and planning processes. It precedes the risk allocation process in the planning phase, but it is performed in conjunction with allocation during the programming and design phases. Risk monitoring and control must continue for the life of the project because risks are dynamic and the list of risks and associated risk management strategies will likely change as the project develops and new risks evolve or anticipated risks disappear.

Periodic project risk reviews repeat the tasks of identification, assessment, analysis, mitigation, planning, allocation, and monitoring and control. Regularly-scheduled project risk reviews can be used to ensure that project risk is an agenda item at all project development and construction management meetings.

If unanticipated risks emerge, or a risk's impact is greater than expected, the planned response or risk allocation may not be adequate. At this point, the project team must perform additional response planning to control the risk.

Key Take-Away

All identified risks need to be managed according to the developed risk plan and the status of each risk needs to be monitored continuously throughout the project.

Tip

Budget time, money, and staff for risk assessment, risk management, and risk response activities.

Resources

- Association for the Advancement of Cost Engineering (AACE) International. 2000. AACE International's Risk Management Dictionary. *Cost Engineering Journal.* 42(4):28–31.
- Department of Energy. 2003. *Project Management Practices, Risk Management.* U.S. Department of Energy. Office of Management, Budget and Evaluation. Office of Engineering and Construction Management. Washington, DC.

- Project Management Institute. 2004. *A Guide to Project Management Body of Knowledge (PMBOK® Guide).* The Project Management Institute. Newton Square, Pennsylvania. 388 pp.

Types of Risks

To reiterate, the first step in an effective risk management program is to identify possible risks. Specific concerns related to nighttime work zones include poor visibility and work quality, staffing issues, unwanted noise and glare, decreased worker and driver alertness, impaired drivers, higher vehicle speeds, increased labor costs, materials and traffic control, and problems in logistics and supervision. These risks are categorized broadly as safety, cost/production and schedule, quality, organizational relationships, technical, construction, economic, and environmental. Table 2.1 provides more detail by risk category and where additional information can be found in this Guidebook.

Tip

Mobile night operations such as painting and patching pose an increased risk to road users and workers because it is rarely feasible to use standard lane closures, visibility is lessened, and driver performance is often decreased. High priority should be given to the use of shadow vehicles with truck-mounted attenuators during all mobile night operations on moderate and high-speed highways (Bryden 2003).

Summary

STAs are shifting toward more nighttime construction. Nighttime construction mitigates the impact of construction operations on the traveling public, can shorten the duration of construction operations, and decreases interruptions to construction activities.

However, nighttime construction operations may be more hazardous for both drivers and construction personnel. Therefore, risk management is extremely important for creating a safe nighttime work zone and successful project.

Although this Guidebook gives an overall idea of the general types of risks that may be involved in nighttime work zones, it should not be followed blindly for all projects. Given that each construction project is unique in nature, the types of risks involved in projects vary from project to project according to the type of project, site conditions, different contract types, contractors and subcontractors involved, and political scenario.

It is extremely important to have a good risk management team assigned for all construction projects. The team should be responsible for identifying and assessing risks according to the specific project and for creating a risk mitigation process.

The risk management team will ideally start work during project conceptualization and continue until project commissioning. Proper risk management provides safe work zones for workers, a safe travelway for motorists, and a successful project.

14 A Guidebook for Nighttime Construction: Impacts on Safety, Quality, and Productivity

Table 2.1. Potential nighttime construction risk details by category.

Potential Risks	Additional Information
Safety	
• Vehicle intrusions into the work zone • Workers struck by construction equipment • Construction equipment intrusion into the operational traffic lanes • Irresponsible driver behavior • High speed of vehicles traversing the work zone • Driver confusion • Poor visibility • Irresponsible worker behavior • Inadequate lighting • Worker fatigue (Elrahman and Perry 1994)	Chapter 8 of this Guidebook has additional safety risk information.
Cost/Production and Schedule	
• Temporary lighting • Additional traffic control measures • Inadequate lighting • Poor visibility • Poor worker morale and fatigue • Availability of supplies and materials • Additional time to set up and take down traffic control devices • Additional time to set up and take down lighting equipment • Coordination with day work activities	Chapter 5 of this Guidebook has additional productivity information and Chapter 7 discusses costs.
Quality	
• Lower quality • Poor visibility • Lighting deficiencies • Difficulty achieving good supervision and inspection • Poor worker morale • Temperatures	Chapter 6 of this Guidebook includes additional information on quality.
Organizational Relationship	
• Lack of communication • Availability of agency decision makers • Availability of design consultants	Chapter 9 of this Guidebook includes information on communication strategies.
Technical	
• Failure to adequately understand circumstances of nighttime work • Modification of specifications for differences	Chapter 3 of this Guidebook has information on illumination.
Construction	
• Productivity • Quality	This Guidebook addresses productivity and quality risks in chapters 5 and 6, respectively.
Economic	
• Construction costs • User costs • Accident costs	Chapter 7 of this Guidebook includes information about the various costs of nighttime work.
Environmental	
• Public relations • Lighting • Community concerns	This Guidebook addresses environmental risks in the Illumination, Nuisances, and Communications chapters (3, 4, and 9).

CHAPTER 3

Illumination

The importance of proper lighting arrangements in nighttime work zones is obvious. Construction work-zone lighting and glare specifications should require appropriate levels of lighting based on work tasks. In addition, the agency must have practical methods for inspecting nighttime work-zone lighting arrangements.

Key Take-Aways

- The more quantitative the contract specifications are about required work-zone lighting levels, the better, because the specifications then provide measurable outcomes that STAs can easily check.
- Drive-through inspections are important but are not sufficient for ensuring proper work-zone lighting levels.

Nighttime construction lighting arrangements have an impact on project safety, quality, cost, and productivity (El-Rayes and Hyari 2005a). One of the main reasons illumination levels have a strong impact on the other aspects of nighttime construction is the fact that light influences human performance and alertness.

Lighting Inspection Tools and Methods

The quality of work-zone lighting can be evaluated using three main parameters: illuminance, lighting uniformity, and glare. A good specification requires a minimum level of average illuminance on the jobsite. This illuminance specification ensures the intensity of light incident on the surfaces of the project. Light uniformity ensures that lighting is distributed equally across the construction jobsite. Finally, the third quality parameter specified is maximum glare, which is quantified using the levels of luminance prevalent on the site (El-Rayes and Hyari 2005a).

Illuminance

Illuminance represents the time rate of light flow, measured in lumens, that falls upon a surface area. The unit of measurement of illuminance is lux, which is measured in lumens per square meter. Illuminance can be measured on a jobsite using a simple device called an illuminance meter (see Figure 3.1).

To calculate horizontal illuminance on a jobsite, measurements need to be taken from different locations. To ensure the uniformity of the measurement, readings over a uniform grid of points that covers the entire jobsite are recommended.

The value of illuminance at any point on the jobsite grid depends on the values of lighting intensity reaching that point from each luminaire being used. The size of the grid for measuring

Figure 3.1. Illuminance meter (El-Rayes et al. 2007).

illuminance depends on the task detail level, but grid point spacing should generally range from 1 to 3 ft.

Key Take-Aways

Illuminance is the amount of light that falls on a surface. It is measured in lux (metric) or foot-candles (imperial). Most agency specifications require certain levels of illuminance for the performance of construction tasks. The measurement is performed by holding the illuminance meter horizontally at the specified height and taking the measurement.

Luminance

The amount of lighting available for performing a specific task can be measured using luminance. This measure is often confused with the above-described illuminance measure; therefore, it is important to distinguish between these two measures. Illuminance is a measure of the amount of light incident on a unit surface area. Luminance, on the other hand, is the amount of light, measured in luminous flux, leaving a surface at a given time. Luminance, therefore, is measured in candelas per square meter and is more suitable for measuring visibility of objects (Ellis 2001).

Given that luminance needs a target for which measurements are taken, its measuring devices allow users to focus from a distance on specific targets. Figure 3.2 shows a typical luminance meter.

Key Take-Aways

Luminance is the amount of light reflected from a surface. Luminance is measured in candela per square meter (metric) or foot-candelas (imperial). Most agency specifications do not have a requirement for luminance, but it is an important parameter to measure because it determines the amount of glare.

Uniformity

Lighting uniformity is an important lighting quality parameter used to evaluate the suitability of lighting arrangements in nighttime work zones. This parameter is based on the calculation of the levels of illuminance on the jobsite. Lighting uniformity is calculated as the ratio between the above-described average illuminance, E_{avg}, and the minimum illuminance at the darkest spot on

Figure 3.2. Luminance meter (El-Rayes et al. 2007).

the jobsite, $E_{min.}$ The following equation shows the above-described calculation of the uniformity ratio (El-Rayes and Hyari 2005a).

$$uniformity\ ratio(U) = \frac{E_{avg}}{E_{min}}$$

Note that smaller values of this ratio are better because they indicate a smaller difference between average illuminance and the levels of lighting at the darkest spot on the jobsite (Nassar 2008).

Glare

Unlike lighting uniformity, glare calculations are dependent on luminance values prevalent on the jobsite. Luminance calculations require consideration of the reflectance characteristics of the surfaces present at the jobsite.

The largest surfaces to consider are naturally the pavement surfaces in the work area, which are classified into four main categories by the International Engineering Society of North America (IESNA) based on the ability of the pavement material to reflect light (El-Rayes and Hyari 2005a).

These pavement reflectance characteristics are used to determine the luminance of the pavement. The importance of pavement luminance stems from the fact that the sensation of glare depends on the amount of veiling luminance experienced relative to the level of luminance the eyes adapt to when exposed to this veiling luminance (in other words, the pavement luminance).

To calculate the glare produced by lighting arrangements, the following three parameters need consideration:

- Observer positions.
- Pavement luminance at possible observer positions.
- Veiling luminance at each observer position.

These positions and lines of sight are used to calculate glare and thereby determine the maximum glare for all positions. This maximum computed glare is the measure used to determine the suitability of work-zone lighting arrangements (El-Rayes and Hyari 2005a).

The calculation of the amount of glare experienced by drivers because of work-zone lighting arrangements starts by determining the likely positions of the drivers and their lines of sight. These positions are determined based on traffic lanes and the expected height from the ground to the drivers' eyes. This height is expected to vary based on the type of vehicle. The determination of possible driver positions and lines of sight is followed by measuring the pavement luminance experienced by drivers at these positions or locations using the luminance meter as explained in the previous sections.

Tip

Glare can be decreased by increasing pavement luminance (by increasing background lighting). This decreased glare is achieved by increasing the lighting ahead of the work zone.

Key Take-Aways

Glare is the ratio of veiling luminance (amount of light falling on the observer's eyes) to pavement luminance (amount of light reflected off pavement surfaces). Pavement luminance can be measured using the luminance meter at a number of targets on the pavement in view of the observer (possible driver of a car passing through the work zone). Vertical luminance, on the other hand, can be measured using an illuminance meter held vertically at the same height as the observer's eyes.

Tip

Increasing the mounting height of the lighting equipment in a work zone decreases glare. This means extending the mast of light towers higher or having higher poles for fixing lights on construction equipment. The trade-off in doing so to decrease glare is that the increased height decreases horizontal illuminance.

Recommended Lighting Levels

A major problem with nighttime work-zone lighting arrangements is the insufficiency of the lighting provided to perform the construction or maintenance task. The level of lighting needed for specific construction activities depends on factors related to the humans performing the activities, as well as factors relating to the task at hand and the environment in which it takes place.

For example, visual ability is a human factor that is known to vary among workers. Therefore, lighting standards assume reasonable visual abilities that are considered to be normal, while giving some allowance for variations among individuals. This assumption allows for visual standards to be based mainly on the visual requirements of the specific tasks construction activities entail.

Table 3.1 provides task-dependent visual standards (Ellis 2001).

Table 3.1. Task-dependent visual standards (Ellis 2001).

Task Dependency	Visual Standard
Required Accuracy	The higher the precision required in a task, the higher the level of illumination needed.
Background Reflection	The ability to visualize an object or a target depends on the contrast between that object and the background. Highly reflective backgrounds decrease the visibility of the target or object.
Relative Speed	The relative speed of the object/target or its observer is another factor directly affecting the level of lighting needed for the construction task. Faster moving objects/targets necessitate higher levels of illumination.
Object Size	The size of the target observed in construction tasks has an impact on the needed level of illumination for the task. The smaller the object, the higher the level of lighting needed.
Seeing Distance	The distance between the observer and the target in each task is another determining factor in setting illumination levels. Larger distances necessitate higher levels of illumination.

Table 3.2. Required illumination levels for highway construction activities (Ellis 2001).

Lighting Category	Minimum Illumination (lx)	Area to be Illuminated	Type of Work Activity	Sample Activities
I	54	Illumination throughout the work area	General work area lighting, and performance of visual tasks of large size, or medium contrast, or low required accuracy	Excavation Sweeping
				General lighting of all work areas and movement areas between tasks
II	108	Illumination of work area and areas adjacent to equipment	Performance of visual tasks of medium size, or low to medium contrast, or medium required accuracy	Paving Milling
				Work areas for the active paving operation
III	216	Illumination of task	Performance of visual tasks of small size, or low contrast, or high required accuracy, or fine finish	Crack filling Signalization systems
				Lighting applied directly to the task

Note: lx is the symbol for lux.

The above-described factors have been used to determine illumination standards in a number of industries. Table 3.2 presents the levels of illumination necessary for major construction activities.

Key Take-Aways

- Recommended illumination levels vary by task.
- Tasks requiring higher levels of precision need higher levels of lighting.
- A minimum illuminance of 54 lux needs to be maintained in general working areas for the safety of workers and the driving public.

Tip

One indication of the adequacy of the levels of illuminance is what could be termed the "no flashlight rule." If the illuminance provided by the lighting equipment on the job is sufficient, field personnel should not need to use a flashlight for additional lighting in a work zone.

Lighting Specifications

A number of STAs have developed good temporary lighting specifications for nighttime highway construction and maintenance activities. Following is a review of some standard specifications.

Illinois

The Illinois Department of Transportation (IDOT) has conducted a number of studies on the appropriate lighting levels for nighttime construction work zones. That work is reflected in their standard specifications that provide details of lighting levels for specific operations. The example in Figure 3.3 specifically addresses the lighting needs for flaggers in nighttime work zones.

The IDOT standard specification does not provide details for the methods used to provide such lighting levels. As a result, the special provision shown in Figure 3.4 was developed based on

IDOT Standard Specifications, Section 701.13 "Flaggers:" For nighttime flagging, flaggers shall be illuminated by an overhead light source providing a minimum vertical illuminance of 10 fc (108 lux) measured 1 ft (300 mm) out from the flagger's chest. The bottom of any luminaire shall be a minimum of 10 ft (3 m) above the pavement. Luminaire(s) shall be shielded to minimize glare to approaching traffic and trespass light to adjoining properties.

Figure 3.3. Sample lighting specifications for flaggers in nighttime work zones (IDOT 2002).

Nighttime Work Zone Lighting:

Effective: November 1, 2008

Description. This work shall consist of furnishing, installing, maintaining, moving, and removing lighting for nighttime work zones. Nighttime shall be defined as occurring shortly before sunset until after sunrise.

Materials. The lighting shall consist of mobile and/or stationary lighting systems as required herein for the specific type of construction. Mobile lighting systems shall consist of luminaires attached to construction equipment or moveable carts. Stationary lighting systems shall consist of roadway luminaires mounted on temporary poles or trailer mounted light towers at fixed locations. Some lighting systems, such as balloon lights, may be adapted to both mobile and stationary applications.

Equipment. The Contractor shall furnish an illuminance meter for use by the Engineer. The meter shall have a digital display calibrated to NIST standards, shall be cosine and color corrected, and shall have an accuracy of ± five percent. The sensor shall have a level indicator to ensure measurements are taken in a horizontal plane.

CONSTRUCTION REQUIREMENTS

General. At the preconstruction conference, the Contractor shall submit the type(s) of lighting system to be used and the locations of all devices. Before nighttime construction may begin, the lighting system shall be demonstrated as being operational.

Nighttime Flagging. The requirements for nighttime flagging shall be according to Article 701.13 of the Standard Specifications and the glare control requirements contained herein.

Lighting System Design. The lighting system shall be designed to meet the following.

(a) Lighting Levels. The lighting system shall provide a minimum of 5 foot candles (54 lux) throughout the work area. For mobile operations, the work area shall be defined as 25 ft (9 m) in front of and behind moving equipment. For stationary operations, the work area shall be defined as the entire area where work is being performed. Lighting levels will be measured with an illuminance meter. Readings will be taken in a horizontal plane 3 ft (1 m) above the pavement or ground surface.

(b) Glare Control. The lighting system shall be designed and operated so as to avoid glare that interferes with traffic, workers, or inspection personnel. Lighting systems with flood, spot, or stadium type luminaires shall be aimed downward at the work and rotated outward no greater than 30 degrees from nadir (straight down). Balloon lights shall be positioned at least 12 ft (3.6 m) above the roadway. As a large component of glare, the headlights of construction vehicles and equipment shall not be operated within the work zone except as allowed for specific construction operations. Headlights shall never be used when facing oncoming traffic.

(c) Light Trespass. The lighting system shall be designed to effectively light the work area without spilling over to adjoining property. When, in the opinion of the Engineer, the lighting is disturbing adjoining property, the Contractor shall modify the lighting arrangement or add hardware to shield the light trespass.

Construction Operations. The lighting design required above shall be provided at any location where construction equipment is operating or workers are present on foot. When multiple operations are being carried on simultaneously, lighting shall be provided at each separate work area. The lighting requirements for specific construction operations shall be as follows.

(a) Installation or Removal of Work Zone Traffic Control. The required lighting level shall be provided at each truck and piece of equipment used during the installation or removal of work zone traffic control. Headlights may be operated in the work zone.

(b) Milling and Paving. The required lighting level shall be provided by mounting a minimum of one balloon light to each piece of mobile construction equipment used in the work zone. This would include milling machines, mechanical sweepers, material transfer devices, spreading and finishing machines, and rollers; but not include trucks used to transport materials and personnel or other vehicles that are continuously moving in and out of the work zone. The headlights of construction equipment shall not be operated within the work zone.

(c) Patching. The required lighting level shall be provided at each patching location where work is being performed.

(d) Pavement Marking and Raised Reflective Pavement Marker Removal/Installation. The striping truck and the attenuator/arrow board trucks may by operated by headlights alone; however, additional lighting may be necessary for the operator of the striping truck to perform the work. For raised reflective pavement marker removal and installation and other pavement marking operations where workers are on foot, the required lighting level shall be provided at each truck and piece of equipment.

(e) Layout, Testing, and Inspection. The required lighting level shall be provided or each active area of construction layout, material testing, and inspection. The work area shall be defined as 15 ft (7.6 m) in front and back of the individual(s) performing the tasks.

Basis of Payment. This work will be paid for at the contract lump sum price for NIGHTTIME WORK ZONE LIGHTING.

Figure 3.4. Sample lighting specifications for nighttime work zones (IDOT 2008).

Standard Specifications for Road and Bridge Construction 2010

Section 8-4.1 Night Work: During active nighttime operations, furnish, place and maintain lighting sufficient to permit proper workmanship and inspection. Use lighting with 5 ft-cd minimum intensity. Arrange the lighting to prevent interference with traffic or produce undue glare to property owners. Operate such lighting only during active nighttime construction activities. Provide a light meter to demonstrate that the minimum light intensity is being maintained.

Lighting may be accomplished by the use of portable floodlights, standard equipment lights, existing street lights, temporary street lights, or other lighting methods approved by the Engineer.

Submit a lighting plan at the Preconstruction Conference for review and acceptance by the Engineer. Submit the plan on standard size plan sheets (not larger than 24 by 36 in.), and on a scale of either 100 or 50 ft to 1 in. Do not start night work prior to the Engineer's acceptance of the lighting plan.

During active nighttime operations, furnish, place and maintain variable message signs to alert approaching motorists of lighted construction zones ahead. Operate the variable message signs only during active construction activities

Include compensation for lighting for night work in the Contract prices for the various items of the Contract. Take ownership of all lighting equipment for night work.

Figure 3.5. Sample lighting specifications for road and bridge construction (FDOT 2010).

two studies IDOT commissioned: *Nighttime Construction—Evaluation of Lighting for Highway Construction Operations in Illinois* (Report No. ITRC FR 00/01-2) and *Nighttime Construction—Evaluation of Lighting Glare for Highway Construction in Illinois* (Pub. No. FHWA-ICT-08-014).

Florida

The Florida Department of Transportation (FDOT) has a slightly more detailed nighttime construction lighting specification. The FDOT specification contains definitive illumination levels that should be achieved and specifies possible lighting equipment that could be used to achieve appropriate lighting levels, as shown in Figure 3.5

New Jersey

The New Jersey Department of Transportation (NJDOT) has an article addressing lighting levels in the General Provisions of its *Standard Specifications for Road and Bridge Construction* (2007a) as shown in Figure 3.6.

The levels of illuminance required are shown in Table 3.3.

In addition, the NJDOT provision has a number of requirements concerning worker visibility during nighttime construction, as shown in Figure 3.7.

108.06 Night Operations

Night operations comprises work performed from 30 minutes before sunset to 30 minutes after sunrise. Before beginning night operations, demonstrate to the Resident Engineer (RE) the method of meeting the specified illuminance levels and visibility requirements for workers and equipment for each planned operation. The Department will determine illuminance levels by taking light meter readings horizontally to the road surface facing the light source. Do not begin night operations until the RE approves the method of meeting the specified illuminance levels and visibility requirements.

Figure 3.6. Sample lighting specifications for road and bridge construction (NJDOT 2007a).

Table 3.3. Sample illuminance-level requirements by work description (NJDOT 2007a).

Work Description	Minimum Level (ft candles)	Minimum Lighting Area
Embankment Excavation Landscaping (seeding and sodding) Mechanical sweeping and cleaning Subgrade	5	General lighting throughout area of operation
Traffic control setup and removal (excluding barrier curb)	5	Lighting on task
Traffic director	5	Lighting on task plus minimum of 50 ft ahead and 50 ft behind employee
Milling HMA paving operation* HMA roller operation*	10	Lighting on task and around equipment plus minimum of 25 ft ahead and 25 ft behind equipment plus 10 ft to each side of equipment
Crack sealing Sawcutting and sealing joints Electrical work Intelligent transportation system work	20	Lighting on task
All work not listed in this table*	10	Lighting on task

* Provide 5 ft candles for the indicated lighting area outside the limits for 10 ft candles to a minimum of 100 ft ahead and 100 ft behind equipment.

New York

The New York State Department of Transportation (NYSDOT) standard specifications for portable work-zone illumination are among the most comprehensive, as shown in Figures 3.8a and 3.8b.

Types of Lighting Equipment

Lighting equipment is in constant development as technologies advance at a very rapid pace. These are the four main types of lighting equipment used traditionally for nighttime work zones: light towers, balloon lighting, Night Lite, and high-mast lighting.

Visibility Requirements for Workers and Equipment:

- Ensure that workers wear a 360 degree high-visibility retroreflective safety garment meeting ANSI/ISEA Class 3, Level 2 standards.
- Uniformly light the hopper, auger, and screed areas of pavers as well as the operator's controls on all machines.
- Conventional vehicle headlights do not meet illuminance requirements. Ensure that moving lighting equipment used for night operations has lights directed ahead and behind the equipment.
- Equip moving equipment with two-inch wide, alternating red and white, conspicuity tape meeting the National Highway Transportation Safety Administration standards. Equip off-road equipment with conspicuity tape along the full length of all four sides. Equip on-road vehicles, including trailers and trailer-mounted devices, with conspicuity tape along the full length of both sides, excluding the cab, and across the rear of the vehicle.
- Prevent or minimize glare that may interfere with traffic or disturb local residents. Perform glare control to the [Resident Engineer's] satisfaction. Glare control may require relocating, aiming, or adjusting lights or providing screens, shields, visors, or louvers on lights.

Figure 3.7. Sample worker visibility specifications (NJDOT 2007a).

NEW YORK STATE DEPARTMENT OF TRANSPORTATION

STANDARD SPECIFICATIONS as of May 1, 2008

619-3.19 Nighttime Operations.

A. Nighttime Operations and Lighting Plan. Thirty days prior to the start of nighttime operations, the Contractor shall submit a written Nighttime Operations and Lighting Plan to the Engineer for approval. The plan shall detail all aspects of the traffic control setup, the functions, responsibilities and identities of the traffic control supervisor and other details as necessary. It shall include a contingency plan identifying foreseeable problems and emergencies that may arise, and the approach that will be used to address them. This plan shall be revised and updated by the Contractor as necessary during the progress of the work to accommodate conditions on the contract.

The Contractor shall submit a Nighttime Operations and Lighting Plan to the Engineer, at a scale and printed size similar to the contract plans and appropriate to adequately describe the work, including the following:

Layout showing location of light towers, including typical spacing, lateral placement and mounting height, and clearly show the location of all lights necessary for all work to be done at night.

Description of light towers to be used and electrical power source.

Specific technical details on all lighting equipment, including brand names, model numbers, power rating and photometric data.

Details of any hoods, louvers, shields or other means to be used to control glare.

Attachment and mounting details for lights to be attached to equipment.

Lighting calculations confirming that the illumination requirements will be met by the layout.

The Contractor shall maintain a supply of emergency flares for use in the event of unanticipated situations such as traffic accidents, equipment breakdowns, failure of lighting equipment, etc.

B. Lighting for Nighttime Operations. Prior to the first night of nighttime operations, the Contractor shall set up and operate the lighting equipment at night as a trial run to demonstrate its ability to establish a safe, properly illuminated, nighttime operation. The Contractor shall furnish the Engineer with a photometer, capable of measuring the level of illumination, for use as necessary to check the adequacy of illumination throughout nighttime operations.

1. Equipment. The Contractor shall supply all lighting equipment required to provide a work zone safe for the workers and traffic. Material and/or equipment shall be in good operating condition and in compliance with applicable safety and design codes.

a. Light Towers. Light towers shall be provided as a primary means of illumination, and shall provide Level I illumination throughout the work space. They may be supplemented to the extent necessary by lighting fixtures mounted on construction equipment to provide Level II or Level III illumination where required for paving, milling and similar moving operations. Light towers shall be sturdy and free-standing without the aid of guy wires or bracing, and shall be capable of being moved as necessary to keep pace with construction operations. Light towers shall be positioned to minimize the risk of being impacted by traffic on the roadway or by construction traffic or equipment.

b. Light Towers on Paving, Milling, and Finishing Machines. If needed to supplement portable and/or trailer-mounted light towers, towers shall be affixed to paving, milling, and finishing machines to provide the required level of illumination for the specified distance in front of and behind the machine. No portion of machine-mounted light towers shall exceed a height of 13 ft above ground. Luminaires shall be aimed and adjusted to provide uniform illumination with a maximum uniformity ratio of 5:1. The hopper, auger, and screed areas of pavers and the operator's controls on all machines shall be uniformly illuminated.

c. Construction Equipment Lights. All construction equipment, including rollers, backhoes, loaders, and other equipment operating in areas not illuminated to a minimum of Level I Illumination, shall be equipped with a minimum of two 500 watt flood lights facing in each direction to provide a minimum of 1 foot-candles of horizontal illumination measured 60 ft in front of and behind the equipment. In areas illuminated to a minimum of Level I, construction equipment may move unescorted. In non-illuminated areas, construction equipment shall be equipped with conventional vehicle headlights, shall be illuminated with flood lights on the vehicle, or shall be escorted to permit safe movement. Headlights shall not be permitted as the sole means of illumination while working.

Figure 3.8a. Sample nighttime operations specifications page 1 (NYSDOT 2008).

Light Towers

Light towers are one of the most commonly used types of portable lighting equipment (see Figure 3.9).

Light towers typically have a power generator, a retractable mast, and two to six lighting fixtures. All of these components are mounted on a trailer that can be towed by a construction vehicle.

d. Equipment Mounting. The Contractor shall provide suitable brackets and hardware to mount lighting fixtures and generators on machines and equipment. Mountings shall be designed so that light fixtures can be aimed and positioned as necessary to reduce glare and to provide the required illumination. Mounting brackets and fixtures shall not interfere with the equipment operator or any overhead structures, and shall provide for secure connection of the fixtures with minimum vibration.

e. Portable Generators. The Contractor shall provide portable generators to furnish adequate power to operate all required lighting equipment. Fuel tank capacity and availability of fuel on site shall be sufficient to permit uninterrupted operation throughout the planned shift. Adequate switches shall be provided to control the various lights. All wiring shall be weatherproof and installed in accordance with 29 CFR 1926 Subpart K requirements. All power sources shall be equipped with a Ground-Fault Circuit Interrupter.

2. Illumination Requirements. Tower-mounted luminaires, whether fixed, portable, trailer mounted, or equipment-mounted, shall be of sufficient wattage and/or quantity to provide the required level of illumination and uniformity over the area of operation.

The uniformity of illumination, defined as the ratio of the average illumination to the minimum illumination over an area requiring an indicated illumination level, shall not exceed 5:1. Illumination levels on approach roadways should be increased sequentially to prevent motorists from becoming disoriented by rapid changes from full dark to very bright conditions.

Existing street and highway lighting shall not eliminate the need for the Contractor to provide lighting. Consideration will be given to the amount of illumination provided by existing lights in determining the wattage and/or quantity of lights to be provided. Such consideration shall be presented in the Contractor's Nighttime Operations and Lighting Plan. In the event of any failure of the lighting system, nighttime operation(s) shall be discontinued until the required level of illumination is restored.

a. Level I (5 foot-candles). Level I illumination shall be provided for all areas of general construction operations to include all work operations by Contractors' personnel, including work zone traffic control set-up and operations, staging, excavation, cleaning and sweeping, spoil disposal, landscaping, planting and seeding, layout and measurements ahead of the actual work, borrow areas, spoil areas, and truck cleanout areas. Level I illumination shall be provided at the area of lane and/or road closure tapers continuously, including the setup and removal of the closure tapers. Level I illumination shall be provided a minimum of 400 ft ahead and 800 ft behind a paving or milling machine, or for the entire area of concrete placement or pavement work if less than 1,500 ft. This area shall be extended as necessary to incorporate all vehicle and equipment operations associated with the paving operation.

The only exception to the requirement for Level I illumination throughout the area of construction operations is that finish rollers can work beyond the area of Level I illumination using floodlights mounted on the roller.

b. Level II (10 foot-candles). Level II illumination shall be provided for flagging stations, asphalt paving, milling, and concrete placement and/or removal operations, including bridge decks, 50 ft ahead and 100 ft behind a paving or milling machine.

c. Level III (20 foot-candles). Level III illumination shall be provided for pavement or structural crack filling, joint repair, pavement patching and repairs, installation of signal equipment or other electrical/mechanical equipment, and other tasks involving fine details or intricate parts and equipment.

3. Glare Control. All lighting shall be designed, installed, and operated to avoid glare that affects traffic on the roadway or that causes annoyance or discomfort for residences adjoining the roadway. The Contractor shall locate and aim lighting fixtures to provide the required level of illumination and uniformity in the work zone without the creation of objectionable glare. The Engineer will determine when glare exceeds acceptable levels, either for traffic or for adjoining residences.

The Contractor shall provide shields, visors or louvers on luminaires as necessary to reduce objectionable levels of glare. As a minimum, the following requirements shall be met to avoid objectionable glare on roadways open to traffic in either direction:

- Tower-mounted luminaires shall be aimed either generally parallel or perpendicular to the roadway.
- Luminaires shall be aimed such that the angle between the center of the beam axis and the vertical mounting pole is no greater than 45E.
- No luminaires shall be permitted that provide a luminous intensity greater than 20,000 candelas at an angle of 72E above the vertical.
- Except where prevented by overhead utilities or structures, towers shall be extended to their full working height when in use to reduce glare and provide uniform illumination.

Figure 3.8b. Sample nighttime operations specifications page 2 (NYSDOT 2008).

The luminaires installed in light towers are usually fitted with 1,000 to 1,500 watt metal halide, high-pressure sodium, or tungsten halogen bulbs. Different bulbs vary in the color of their light and in the time it takes for them to warm up (Gambatese 2005).

Light towers have a number of features that increase their versatility and flexibility in lighting outdoor space. The retractable masts can be raised to 30 ft and rotate 360 degrees around their vertical axis. These towers can light areas ranging from five to seven acres using only four luminaires.

Figure 3.9. Typical light tower (El-Rayes et al. 2007).

Balloon Lighting

Balloon lights are intended for use as equipment-mounted lights or in stationary locations such as flagger stations (Figure 3.10). These lights have fabric covers that are inflated with air or helium and they can be mounted on stands.

The source of light enclosed in the fabric cover is either a halogen bulb or a Hydrargyrum Medium-arc Iodide (HMI) system. Balloon lights can illuminate spaces ranging from 108,000 to 432,000 sq ft.

The main advantages of balloon lighting are that it distributes light over 360 degrees, offers glare-free lighting, and can be mounted as high as 164 ft (Gambatese 2005).

Nite Lite

A new equipment type that was utilized in an IDOT test was the Nite Lite (see Figure 3.11).

The Nite Lite was a portable light composed of a 400-watt metal halide lamp in a dome-shaped casing coated with a light-diffusing material. The luminaire had a weight of 11.8 kg, and the dome had a diameter of 0.635 m.

Figure 3.10. Balloon lights (El-Rayes et al. 2007).

The luminaire was powered by a 120-volt AC source that could produce up to 42,000 lumens, which could provide lighting for an area of 1,395 sq m (El-Rayes et al. 2007).

High-Mast Lighting

The fourth type of construction lighting is a semi-permanent lighting system for the illumination of work zones. High-mast lighting systems are composed of luminaires mounted on high-mast poles. These were first used by the NYSDOT in 2005 for a three-mile stretch of I-90 at Albany, New York (see Figure 3.12) (Freyssinier et al. 2008).

The system was proposed as an alternative for portable light towers. The photo shows this test section and the high-mast lighting system.

Table 3.4 shows the main characteristics of high-mast lighting systems, including the horizontal illuminance produced. The measurements were taken in conditions that had no ambient background lighting and followed IESNA measurement guidelines.

The average illuminance the system produces is more than 100 lux, which is sufficient for the movement of construction workers and some construction activities such as pavement resurfacing (Freyssinier et al. 2008).

The results of the evaluation of the system's performance showed that it met lighting quality specifications for nighttime work zones. The comparison of the performance of high-mast lighting to portable light towers showed it provided sufficient illumination with fewer shadows and relatively low glare.

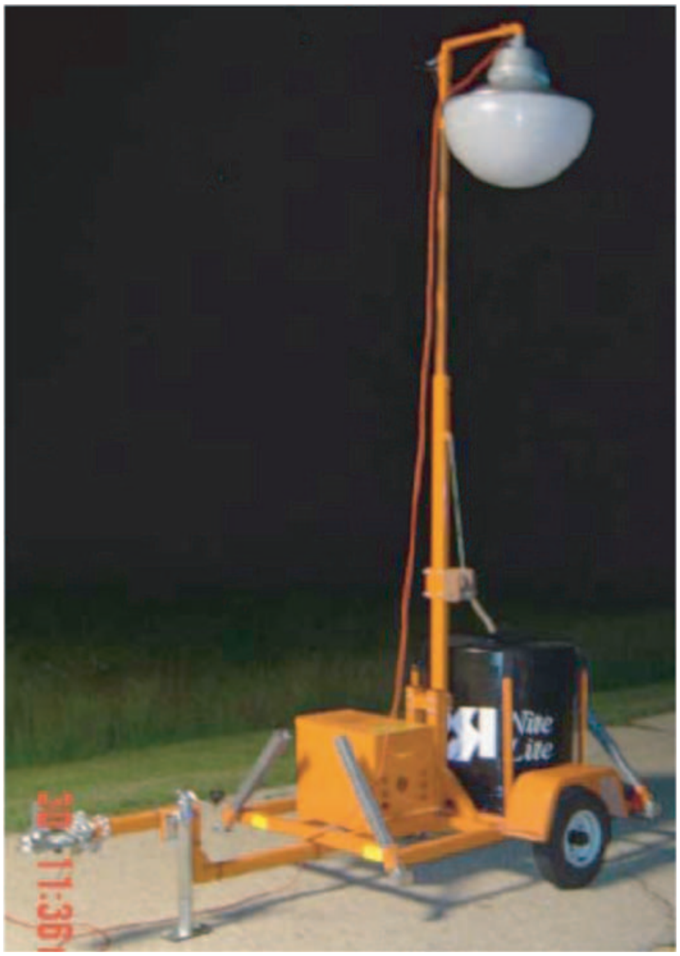


Figure 3.11. Nite Lite lighting equipment (El-Rayes et al. 2007).

Figure 3.12. Test stretch for high-mast lighting (Freyssinier et al. 2008, photo Dennis Guyon, Lighting Research Center).

Table 3.4. Lighting properties of high-mast lighting systems (Freyssinier et al. 2008).

Category/Item	Value
Photometric Characteristics	
Total number of pole locations	108
Mounting height	70 ft
Typical pole spacing (staggered layout)	320 ft between poles on same side of road
Number of luminaires per pole	4
Total number of luminaires	432
Lamp type per luminaire	Metal halide, 1,500 W
Lamp life	7,000 to 8,000 h
Predicted Illuminance on Pavement (Software Calculation)	
Average	133 lx
Maximum	233 lx
Minimum	80 lx
Average to minimum ratio	3.0:1
Maximum to minimum ratio	2.9:1
Actual Illuminance on Pavement (Measure on Site)	
Average	148 lx
Maximum	209 lx
Minimum	101 lx
Average to minimum ratio	1.5:1
Maximum to minimum ratio	2.1:1
Electrical Characteristics	
Input power per luminaire	1,564 W
Total installed load for lighting	675.6 kW
Number of generators installed	5
Total power available per generator	250 kW
Total installed generation capacity	1,250 kW

Key Take-Aways

- Light towers are the most common type of construction lighting equipment. Light towers are suitable for lighting large stationary areas.
- Balloon lights are used for lighting small to medium stationary areas or can be equipment-mounted.
- High-mast lighting is a new type of lighting that is semi-permanent in nature.

Tip

Agencies do not usually prescribe the lighting equipment used by contractors to provide appropriate lighting levels. Therefore, most contractors select lighting equipment based on availability and price. These criteria may not result in equipment that results in optimum lighting arrangements. Therefore, attention should be given to contractor-submitted lighting plans and proposed equipment.

Resource

IESNA pavement reflectance categories can be found in the American National Standards Institute (ANSI)/IESNA RP-8-00 report, which is available online at http://www.scribd.com/doc/38492536/Ansi-Iesna-Rp-8-00.

CHAPTER 4

Nuisances

The FHWA commitment to minimizing noise impacts and enhancing the noise environment is described in *Title 23 CFR Part 772—Procedures for Abatement of Highway Traffic Noise and Construction Noise.* This regulation addresses noise impact assessment and abatement.

In addition, each STA is empowered to define certain terms and conditions found in 23 CFR 772, such as the cost-effectiveness criteria by which candidate noise mitigation measures are evaluated for feasibility and reasonableness. Typically these cost-effectiveness guidelines account for the cost of a given mitigation measure (e.g., noise barrier), the decibel reduction, and the number of people or properties (dwelling units, businesses) expected to benefit from the mitigation.

Key Take-Away

23 CFR 772.11 (g)

The plans and specifications will not be approved by the FHWA unless those noise abatement measures that are reasonable and feasible are incorporated into the plans and specifications to reduce or eliminate the noise impact on existing activities, developed lands, or undeveloped lands for which development is planned, designed, and programmed.

However, FHWA and state DOT guidelines do not mandate that construction noise be evaluated and/or mitigated in any specific manner; they simply provide guidelines and recommendations for each project to adopt on a case-by-case basis.

Project design and contract documents can address nuisances by specifying the sequencing of construction operations to minimize nuisance impacts. Practices such as source, path, and receptor control are helpful in eliminating or minimizing the effect of nighttime construction nuisances.

The major nuisances associated with nighttime construction are noise, illumination, and vibration (Schexnayder and Ernzen 1999). Noise problems are normally caused by the operation of heavy equipment and specifically by vehicle and machine backup alarms. While good illumination is necessary for the work to proceed at night and for the safety of the traveling public, proper work-zone illumination can be very intrusive to project neighbors. Vibration problems are primarily a result of pile driving, hoe ram demolition, blasting operations, or the use of vibratory rollers.

Agencies need to be aware that they are exposed to possible contractor claims if noise limitations are not properly stated in contract documents. Contract documents must be checked to ensure there are no conflicts between bonus clauses for early completion and specifications limiting work activities to daytime hours because of community noise regulations.

FDOT Standard Specifications: Section 7, Article 7-1 **Laws to be Observed**, Sub-article 7-1.1, "The contractor is required to become familiar with and comply with all Federal, State, county and city laws, by-laws, ordinances and regulations that control the actions or operation of those engaged or employed in the work or that affect materials used."

FDOT Standard Specifications: Section 8, Article 8-4 **Limitations of Operations**, Sub-article 8-4.1, "Night Work," "The contractor is required to comply with all applicable regulations governing noise abatement."

Plan Sheet M-13 **Pile Driving**, Note 1 stated, "All pile driving activities are subject to the Noise Ordinance of the City of Jacksonville."

Figure 4.1. Sample noise ordinance contract language.

The problems associated with nighttime construction are location dependent. Nighttime construction can cause nuisances when the work is in residential and commercial areas, whereas few problems arise in rural settings or when resurfacing a highway in an industrial area.

From earlier studies, it is evident that for projects involving nighttime work, the "contract documents must clearly define work restrictions (e.g., work hour restrictions, vibration and noise restrictions, and any regulations that will limit work or logistic activities). These restrictions must be further delineated as to their application to activities during daylight hours or to evening and nighttime hours with definitions of the terms daylight, evening, and nighttime clearly stated" (Anderson and Schexnayder 2009).

Nuisance problems are a function of the nature of the nighttime work performed and the location of that work. Conversely, agencies experience limited nuisance problems when conducting the nighttime activities of paving, patching, or resurfacing operations on Interstate highways. These operations typically take place where the background noise from the traffic masks the construction noise. In addition, this type of work involves operations that are constantly moving and, therefore, affect a receiver for only limited durations.

STAs can control noise at the source by requiring adherence to certain noise (decibel) limits during nighttime construction or by prohibiting otherwise unmitigatable loud devices (such as pile drivers). In many cases, limits are the consequence of specific local ordinances. While in some locations STAs do not have to abide by city regulations, the contract language should still make contractors aware of the noise ordinance and hold them in conformance.

Figure 4.1 has the contract language used to inform contractors of the Jacksonville, Florida, noise ordinance.

FHWA Noise Guidance Documents

The FHWA Environmental Policy Statement establishes a commitment to ensure that all feasible and reasonable mitigation measures are incorporated into projects to minimize noise impacts and enhance the surrounding noise environment to the extent practicable. This commitment to minimize noise impacts and enhance the noise environment is described in the FHWA noise regulation, *Title 23 CFR Part 772—Procedures for Abatement of Highway Traffic Noise and Construction Noise.*

Resource

FHWA is the primary regulatory authority regarding noise impact assessment and abatement. *Title 23 CFR Part 772—Procedures for Abatement of Highway Traffic Noise and Construction Noise* is available online at www.fhwa.dot.gov/legsregs/directives/fapg/cfr0772.htm.

Note that FHWA updated 23 CFR Part 772, effective July 13, 2011, to place more responsibility on STAs to define acceptable mitigation criteria. However, the portion of 23 CFR Part 772 that deals with construction noise (Section 772.19) remained essentially unchanged, as shown in Figure 4.2.

Section 772.19, which is very short, deals with construction noise and identifies three general steps to perform for all projects:

- Identify land uses or activities that may be affected by noise from construction of the project. The identification is to be performed during the project development studies.
- Determine the measures that are needed in the plans and specifications to minimize or eliminate adverse construction noise impacts to the community. This determination shall include a weighing of the benefits achieved and the overall adverse social, economic, and environmental effects as well as the costs of the abatement measures.
- Incorporate the needed abatement measures in the plans and specifications.

Figure 4.2. FHWA construction noise mitigation requirements.

To support agencies in their efforts to control construction noise nuisances, FHWA sponsored development of a *Construction Noise Handbook* (FHWA 2006a) and associated *FHWA Roadway Construction Noise Model (FHWA RCNM)* (FHWA 2006b). This handbook and noise prediction model spreadsheet are the successors to the 1977 Special Report—*Highway Construction Noise: Measurement, Prediction and Mitigation* (Reagan and Grant 1977). Supporting the 1977 Special Report was a *Symposium on Highway Construction Noise* report by Dames & Moore (1977) that also provides information to address construction noise problems.

Resources

- *Construction Noise Handbook*
  http://www.fhwa.dot.gov/environment/noise/construction_noise/handbook/index.cf
- *FHWA Roadway Construction Noise Model (FHWA RCNM)*
  http://www.fhwa.dot.gov/environment/noise/construction_noise/rcnm/rcnm.cfm

There are a number of construction-noise case histories that focus attention on construction noise evaluation and control. A recent example is that of the Central Artery/Tunnel (CA/T) project (also known unofficially as the Big Dig) in Boston, Massachusetts, which proved that mega-project construction noise can be controlled satisfactorily while the work proceeds (Thalheimer 2000).

Sound

Sound is energy in motion as a pressure wave through the air produced by a vibrating body. A decibel (dB) is the basic sound level unit; it denotes a ratio of intensity to a reference sound.

Most sounds that humans are capable of hearing have a decibel range of 0 to 140. Zero dB, by international agreement, corresponds to an air pressure level of 20 micro-Pascals (in other words, the agreed-upon threshold of hearing). A whisper is about 30 dB, conversational speech is about 60 dB, and 130 dB is the threshold of physical pain.

Humans sense the intensity difference of one sound from another. A three-decibel change in noise level is a barely noticeable difference, while a 10-dB change is perceived subjectively as a doubling/halving in loudness.

In the case of the general population, a five-decibel change is easily noticeable by most people. To facilitate the measurement of sound stimuli perceived by humans, a weighted decibel scale (called A-weighted) is used to simulate the frequencies heard by humans. A decibel that is measured or calculated using this frequency adjustment is called an A-weighted decibel, and abbreviated as dBA.

Sound fluctuates with time and is emitted from multiple sources from moment to moment; consequently, the common practice is to evaluate the temporal characteristics of sound with various statistical metrics much as its maximum (Lmax) or minimum (Lmin) levels. One of the more common metrics is the equivalent sound level, or Leq, which amalgamates all sound information into a single energy-averaged level. The Leq value is the average acoustic intensity over a defined time period and represents the equivalent energy level of a fluctuating sound, had that sound been steady over the time period.

Environmental sound can also be presented on a statistical basis using percentile sound levels (Ln), which refer to the sound level exceeded for a specified percent of the time. Thus, an L_{10} nomenclature would mean an A-weighted sound level exceeded 10 percent of the time. In the case of construction noise, the L_{10} has often been found to be about three decibels greater than the Leq level and correlates well with construction activity (Thalheimer 2000).

When dealing with the public, sound and noise are not the same thing. While sound is preferable and pleasant, it can become noise when any of the following occurs with regard to the sound for the receiver:

- Too loud.
- Unexpected.
- Uncontrollable.
- Pure tone components.

Noise is any sound that has the potential to annoy or disturb humans, or cause an adverse psychological or physiological effect on humans.

Equipment Noise

Most construction noise is the result of equipment operation. The equipment type, specific model, equipment condition, and operation being performed influence equipment noise. Newer equipment is noticeably quieter than older models, due primarily to better engine housings and mufflers, and fan design. Table 4.1 shows noise levels generated by typical equipment.

Noise Control

Physical noise control seeks a reduction and/or modification of a perceived sound field. It strives to change the noise level or impact at the receiver. Mitigation of annoying noise should consider source, path, and receptor control. However, noise is also psychological. Therefore, community involvement is a critical component of noise nuisance mitigation. Nuisance issues can be defused substantially by recognition of community concerns and a willingness to address specific concerns.

Resource

The FHWA construction noise website at www.fhwa.dot.gov/environment/noise/construction_noise contains these important resources:

- *Construction Noise Handbook* prepared by the John A. Volpe National Transportation Systems Center.
- *FHWA Roadway Construction Noise Model* prediction spreadsheet.
- *Highway Construction Noise—Measurement, Prediction, and Mitigation Manual.*

Community Involvement

Community involvement is a vital part of every nuisance mitigation program, whether the issue is noise, vibration, or light. Maintaining positive community relations in unison with physical nuisance monitoring and mitigation measures is important. Public involvement helps to eliminate potential problems before they become major issues.

Table 4.1. Construction equipment noise emission levels (Thalheimer 2000, originally from CA/T Project, adopted by FHWA RCNM and NYCDEP Rules).

Equipment Type or Activity	Lmax Noise Limit at 50 ft, Slow (dB)	Is Equipment an Impact Device?	Acoustic Usage Factor (%)
Auger drill rig	85	No	20
Backhoe	80	No	40
Blasting	94	Yes	1
Chain saw	85	No	20
Compactor (ground)	80	No	20
Compressor (air)	80	No	40
Concrete batch plant	83	No	15
Concrete mixer truck	85	No	40
Concrete pump	82	No	20
Concrete saw	90	No	20
Crane	85	No	20
Dozer	85	No	40
Dump truck	84	No	40
Excavator	85	No	40
Flatbed truck	84	No	40
Front-end loader	80	No	40
Generator (≤25 KVA)	70	No	50
Generator (>25 KVA)	82	No	50
Grader	85	No	40
Boring hydraulic jack	80	No	25
Impact pile driver	95	Yes	20
Jackhammer	85	Yes	20
Hoe ram	90	Yes	20
Paver	85	No	50
Pickup truck	55	No	40
Pneumatic tools	85	No	50
Pumps	77	No	50
Rock drill	85	No	20
Scraper	85	No	40
Slurry plant	78	No	100
Slurry trenching machine	82	No	50
Soil mix drill rig	80	No	50
Tractor	84	No	40
Vacuum street sweeper	80	No	10
Vibratory concrete mixer	80	No	20
Vibratory pile driver	95	No	20
Welder	73	No	40

NYCDEP = New York City Department of Environmental Protection.
KVA = Kilovolt amperes.
Impact Device = Equipment is assumed to produce separate discernible sound pressure maxima.
Acoustic Usage Factor = Percentage of time equipment is assumed to be running at full power while working on site.

Tip

Effective community awareness techniques:

- Personal contact via door-to-door visits or special gatherings.
- Personalized letters.
- Newspaper and radio announcements.
- Website-based project information.

By working with local government officials, businesses, and individuals located adjacent to the project, it is possible to identify and address nuisances. A good practice is to conduct public meetings even if they are not mandatory.

Public meetings are important for receiving feedback and in providing early identification of controversial issues. It is imperative to explain the details of construction phasing and methods and the resulting noise, vibrations, and other nuisances. Likewise, steps to minimize impacts should be stated clearly and project contact information given in case a member of the public feels the need to register a complaint.

All outcomes from communications with the public need to become part of the applicable environmental record. Approved noise abatement measures should also be documented in the appropriate environmental commitments.

Tip

Communications need to educate the public about the following:

- Positive impacts of the completed project (highlight improvements).
- What to expect—work hours, type of work, type of equipment, and nuisance duration.
- Actions to mitigate nuisances.
- Where to get more information.
- How to voice complaints.

It is important to provide accurate and easily accessible information. Depending on the size and scope of the project, different methods can be used to inform the public or to ensure that affected neighbors are informed.

The other equally important part of successful communications is listening. The agency needs to show sensitivity to community concerns and respect for residents and business owners. A significant portion of the listening and response effort will be simply to answer questions. Listening and sensitivity create and strengthen a bond of trust with affected individuals.

Tip

Inform the public via the following:

- Door-to-door visits.
- Neighborhood letters or fact sheets.
- Local media, newspaper notices, press releases, news conferences.
- Public informational workshops.
- Information kiosks in public areas (shopping malls).
- Speakers bureau.
- Brochures/newsletters.
- Project websites.

Complaints will arise during the construction phase, so an established procedure for receiving, tracking, and ensuring a timely response to all grievances is needed. Procedures for handling complaints effectively include the following:

- Have a knowledgeable individual to field all questions.
- Establish a hotline to receive and log any/all queries.
- Develop a system to ensure that all queries are answered in a timely manner.
- Anticipate potential impacts and have a plan in place to minimize those impacts.

Have trained project staff that are able to respond to complaints immediately, investigate/evaluate the severity thereof, and order immediate mitigating actions if the situation warrants.

Tip

Provide project inspectors with cell phones to ensure a quick response to citizen inquiries and complaints. In the case of a major project, inquiry calls can be processed through a central control center, which then notifies the correct inspector. However, for small jobs, the inspector's number should be posted and circulated in the abutting neighborhood.

While noise is usually the primary cause of nuisance complaints, visual impacts also draw attention to the construction process. Large trucks using residential streets for project access create noise, but they also draw attention to the work.

All potential impacts are important considerations, so contract documents need to include appropriate restrictions. When a project is located close to businesses and sound barriers are specified, it may be necessary to include requirements concerning their exterior appearance. Replacement signage may be necessary to maintain public awareness of and access to commercial storefronts.

Source Control

Source control is the most effective method of eliminating noise problems. Source controls, which limit or avoid noise emissions, are the easiest to oversee on the project.

An agency has complete control of the project site and can specify source noise limitations. Once a sound is created, path control methods can be used, but those control techniques only provide partial control of the nuisance.

Source control preempts alternative mitigation efforts. Table 4.2 provides rules of thumb for evaluating the ease and effectiveness of mitigating noise problems.

For example, if two sources are each contributing 60 dBA at a receptor location, the additive or total noise will be 63 dBA as shown in Table 4.3. Conversely, if two noise sources differ by more than 10 decibels, the contribution of the quieter source can be ignored when considering the overall level (L).

Key Take-Away

The noise of each individual piece of equipment, even the loudest noise source, is not always the number one priority. Decibels are logarithmic quantities, not linear; therefore, sound levels cannot simply be added, subtracted, or averaged together.

Source Control through Design Considerations and Specifications

Early communications between project designers and the community can aid greatly in sequencing construction operations to minimize construction noise impacts at sensitive receptors. Abatement measures need to be incorporated into the plans and specifications of the project.

Table 4.2. Source control mitigation by decibel reduction and difficulty level (Schexnayder and Ernzen 1999).

Decibel Reduction	Difficulty Level	Typical Mitigation
5	Simple	Require new equipment
10	Attainable	Equipment modification
15	Very difficult	Possibly by going to alternate methods
20	Nearly impossible	

Table 4.3. Addition of sound levels, L_1 and L_2 ($L_1 > L_2$) (Schexnayder and Ernzen 1999).

$L_1 - L_2$ (dBA)	Add to L_1 (dBA)
0 or 1	3
2 or 3	2
4 to 8	2
≥ 9	0

Project specifications should require that permanent noise barriers (as in traffic noise barriers) be constructed as early as possible to decrease potential construction noise impacts. Alternate construction methods and equipment can also be suggested or specified to lessen potential construction noise impacts (such as cast-in-place piles rather than driven piles).

Specifications. Good controlling specifications are an effective tool in mitigating the effect of construction noise nuisances. Supplemental standard provisions can specify mitigation measures on a contract-by-contract basis to address special local-condition noise. The existence and importance of noise control specifications need to be emphasized at pre-bid and pre-construction conferences.

When the requirement to comply with all restrictions and commitments to local governing bodies is included in the contract documents, contractors can be expected to allow for compliance in the bid price. Such an approach allows contractors to plan their operations effectively and to seek innovative solutions to the clearly identified problem. This approach minimizes potential complaints and serves to control construction cost and delays.

It is often too late to control a contractor's noise by contractual means once work has begun. Therefore, a comprehensive noise control specification must be developed proactively and included in the project bid documents. Doing so will ensure the lowest cost through the competitive bid process and give project managers the means to oversee and direct the contractor in noise-related matters, should field conditions dictate the necessity.

Contract specification tasks include the following:

- Develop contract-specific nuisance evaluation measures.
- Identify noise-sensitive receptors.
- Develop criteria for lot-line and/or emission-noise limits.
- Prohibit specific types of construction activities (certain types of activities can generate noise complaints even though their sound levels do not exceed emission limits, and this is especially true for rattling, banging, tonal, and repetitive sounds).
- Set equipment noise emission limits (see Table 4.1 for typical noise emission levels).
- Establish operational (working-hour) constraints.
- Provide noise abatement incentives for contractors (it may be effective to pay bonuses for staying below noise standards over certain contract periods).
- Include provisions for temporary variances.
- Detail required submittals of mitigation measures.
- Require contractors to prepare detailed noise mitigation plans.

As a minimum, the contractor's noise mitigation plan should include the following:

- Name of responsible party with phone number.
- Distance to receptors for each major noise-generating activity.
- Dates and hours of work by principal type or phase of work.
- Major noise-generating equipment or activity.
- Estimate of construction noise levels at receptors.
- List of noise mitigation measures and the expected noise reduction.

Resource

The New York City Department of Environmental Protection (NYCDEP) Construction Noise Mitigation Plan sample form can be found at http://nyc.gov/html/dep/pdf/noise_mitigation.pdf. The sample explains to the user the required plan elements that a responsible party must include when the listed devices will be used on a construction site (NYCDEP 2007).

Table 4.4. Construction noise limits by receiver lot-line land use and time of day (CA/T Project, Boston).

	Daytime (7 a.m. – 6 p.m.)		Evening (6 p.m. – 10 p.m.)		Night (10 p.m. – 7 a.m.)	
Land Use	L10	Lmax	L10	Lmax	L10	Lmax
Noise-sensitive (Residential)	75 or Baseline +5	85 90 Impact	Baseline +5	85	Baseline+5 if <70 Baseline+3 if ≥70	80
Commercial	80 or Baseline +5	none	none	none	none	none
Industrial	85 or Baseline +5	none	none	none	none	none

When an agency writes requirements based on Table 4.4 and the associated Tip into a project specification, the contractor must comply with both relative lot-line noise limits and absolute equipment sound emissions. Such source control actions serve as measurable contract performance limits against which noise complaints can be evaluated. If conditions causing a noise complaint are found to exceed specified limits, project staff can order the contractor to implement additional mitigation, or even stop work, without fear of incurring a claim from the contractor for unjustified cost or delay.

Tip

Equipment Specification Absolute Noise Criteria

The contract can set "absolute" sound criteria for generic classes of equipment. The data in Table 4.1 are the equipment-specific Lmax noise limits in A-weighted decibels, evaluated at a reference distance of 50 ft, which were specified by the CA/T project in Boston. These limits were set conservatively low to require the use of modern, well-maintained equipment. Every piece of equipment must be pre-certified by the contractor's acoustical engineer before the machine is allowed to work on the project site.

Other Specification Items. Specifications must be definitive with actual times or other requirements stated clearly; otherwise, there will be contractor versus agency confrontation concerning implementation of the specifications. Other noise source control items that agencies have written into specifications include the following:

- The use of impact pile drivers and hoe rams shall be prohibited during evening and nighttime hours.
- All jackhammers and pavement breakers used on the construction site shall be fitted with manufacturer's approved exhaust mufflers.
- The use of pneumatic impact equipment (i.e., pavement breakers, jackhammers) shall be prohibited within 200 ft of a noise-sensitive location during nighttime hours.
- The local power grid shall be used wherever feasible to limit generator noise. No generators larger than 25 kilovolt amperes (KVA) shall be used and, where a generator is necessary, it shall have a maximum noise muffling capacity.
- The contractor shall minimize noise from the use of backup alarms using measures that meet OSHA (Occupational Safety and Health Administration) regulations. This allows for use of self-adjusting backup alarms, use of manual alarms on low setting, use of observers, and scheduling of activities so that alarm noise is minimized (straight drive-through haul patterns) or

- All equipment with backup alarms operated by the contractor, vendors, suppliers, and subcontractors on the construction site shall be equipped with either audible self-adjusting backup alarms or manual adjustable alarms. The self-adjusting backup alarms shall automatically adjust to five decibels over the surrounding background noise levels. The manually adjustable alarms shall be set at the lowest setting required to be audible above the surrounding noise. Installation and use of the alarms shall be consistent with the performance requirements of the current revisions of the Society of Automotive Engineering (SAE) J994, J446, and OSHA requirements.
- All variable message/sign boards shall be solar powered or connected to the local power grid.
- Material storage areas will be restricted from areas near residences.
- Contractors shall use approved haul routes to minimize noise at residential and other sensitive noise receptor sites.
- A construction noise monitoring program is essential to reassure the public, evaluate any noise complaints, and hold the contractor accountable to noise limits.

Sometimes an agency will even specify the sequence of operations/activities (order of pile driving, work zones close to abutters only during the daytime, other zones at any time).

Noise Monitoring Program

Depending on the type and comprehensiveness of the noise control specification, noise measurements may need to be performed at neighborhood receptor locations prior to construction to determine ambient noise conditions. These ambient measurements are usually performed over several days and nights, including weekday and weekend time periods. The results can then be used to establish acceptable noise criteria limits when construction begins.

Noise measurements need to be performed during construction to ensure that the contractor operations are within established noise limits. Noise monitoring during construction can include measuring cumulative noise at various locations to evaluate compliance with receptor noise limits or noise levels in close proximity to equipment working on a site to ensure acceptable equipment noise emission levels (see Table 4.1).

Tip

The instrumentation used to measure ambient and/or construction noise levels should comply with ANSI Standard S1.4 for Type 1 or Type 2 accuracy. Common noise metrics that are found in various project noise control specifications include the Lmax, the Leq, and statistical levels (L10, L90) exceeded a given percentage of the time. Unless otherwise specified, noise levels should be measured in A-weighted decibels using a root-mean-square (RMS) “slow” time response.

Path Control

Having exhausted all possible mitigation methods of controlling noise at the source, the second line of attack is to control noise propagation along its pathway. Noise barriers can provide a substantial reduction in noise levels and are cost effective, but their use must be implemented in a practical manner without limiting work-area access.

Barriers do increase a project’s visual impact. This visual change can have either a positive or a negative impact, because equipment that is out of sight is often perceived as being less annoying. Therefore, aesthetic effects must be considered when designing barrier systems (Farnham and Beimborn 1991).

Key Take-Away

Physical Placement and Height of the Barrier Wall Control Effectiveness

When placed properly, a noise barrier can provide 5 to 20 decibels of noise reduction from a listener's perspective. The barrier must intervene and completely break the line of sight between the noise source and the receptor. Therefore, the barrier should be placed as close to the noise source or as close to the receptor as possible.

The limiting aspect for a barrier's noise reduction performance is the noise diffracting over the top of the barrier. To ensure that noise does not transit directly through the barrier, its surface density should be 3 lbs per sq ft or greater. Many common barrier materials satisfy this surface density requirement including wooden timbers, lightweight concrete, dense plastics, or engineered metal panels.

Because of practical height limitations for building temporary barriers, mitigating noise that affects the upper stories of tall buildings with barriers can be difficult. Therefore, while the primary intent is for mitigation of ground floors and outdoor use areas, further analysis may be performed in an attempt to mitigate noise for higher floors as site-specific terrain conditions allow. However, extreme care must be practiced when erecting taller noise barriers to ensure they do not tip over due to wind load and, in certain locations, a seismic evaluation is also advisable.

Path Mitigation Techniques

Only reflection, diffraction, insulation, or dissipation can modify an established airborne sound field. Therefore, the three techniques for path mitigation are as follows:

- Distance.
- Reflection.
- Absorption.

By doubling the distance between the source and the receiver, a 3 to 6 dB reduction can be achieved, and a 6 dB reduction represents a noticeable change in noise level.

Barriers are intended primarily to reflect sound away from sensitive receptors effectively. However, the reflected sound energy can travel back toward the source and possibly have an impact on receptors in the other direction.

In these cases, barriers with acoustically absorptive faces may be necessary. Absorption, while occasionally useful to avoid unwanted reflections or for use inside enclosures, should not be viewed as a practical construction noise pathway control measure by itself. Absorption does nothing to reduce the direct sound field and only works to absorb a portion of the sound that actually interacts with the absorptive materials.

Enclose Stationary Equipment

Enclosures can provide a 10 to 20 dB sound reduction; however, caution must be practiced to ensure that enclosed equipment has a sufficient air supply to operate and does not overheat. To be most effective, noise enclosures should cover a noise source completely without any gaps or holes that allow noise to escape. Whenever possible, it is advisable to line the inside of the enclosure with some type of acoustical absorptive material, taking care to avoid interfering with the operation of the equipment.

Figure 4.3 shows an example of an enclosure specification.

Noise Barriers and Curtains

A 5 to 20 dB sound reduction can be achieved using barriers. A sound wave striking a barrier is affected in three ways: some of the sound energy is transmitted through the barrier, some is

All jackhammers and pavement breakers used at the site shall be enclosed with shields or acoustical barrier enclosures.

Figure 4.3. Sample enclosure specification.

absorbed within the material of the barrier, and the majority of the sound energy is reflected back toward the source.

The ability of a barrier to resist the flow of sound energy is largely determined by its mass. Heavy, dense materials are good barriers, whereas soft, porous materials are poor barriers.

A characteristic of a barrier that must always be considered is stiffness. A barrier constructed from a rigid material can transmit vibration and reradiate noise on the backside of the barrier. An approach to the reflected noise problem is to provide noise-absorptive surfaces on the side of the barrier wall facing the noise source.

Barrier design and construction must incorporate consideration of aesthetics and public safety. A tall barrier placed close to a building façade can create a tunnel effect. The creation of such dark spaces can be dangerous to the public that must use the adjoining sidewalk. Barriers constructed of transparent materials (such as Plexiglas or Lexan) can be appropriate in such locations.

A structural and wind load analysis must be conducted before erecting barriers. Thickly-grown non-deciduous bushes and trees can be effective in decreasing sound reflection from walls, but they do not provide noise shielding. Trees and shrubs should not be presented to the public as an effective noise barrier option.

In general, noise barriers or curtains are most cost effective when they provide perceptible noise reduction benefits to a relatively large number of receptors. To provide this, the barrier must physically fit in the space available and completely break the line of sight between the noise source and the receptors.

Tip

A minimum performance requirement to justify barriers is a five-decibel noise reduction at receptor locations; however, it is not uncommon to see performance design goals in the 7 to 10 decibel range.

Barrier Specifications. Solid barriers should be constructed of a material having a surface density of at least 3 lbs per sq ft to ensure adequate sound transmission loss. The most commonly used reference to quantify a material's ability to decrease transmitted noise is its sound transmission class (STC) rating. A material's STC is determined in accordance with American Society for Testing and Materials (ASTM) Test Method E90 by measuring the noise energy reduction through the material as a function of frequency and then evaluating the results against a standard frequency-shaped curve with the resulting rating taken at 500 Hz.

Key Take-Away

Noise barriers should have STC ratings of at least 25, with 30 being a more desirable value.

Gaps through or under noise barriers seriously degrade the sound-mitigating effect of a barrier. Gaps should be sealed with material that completely closes the openings and attenuates sound. However, access gaps are often required in barriers. At such locations, two barrier segments should be overlapped to provide access. The overlap causes the sound to "bend" several times before heading toward the neighbors. A 15 to 20 foot overlap is generally sufficient.

> Noise barriers shall break the line of sight between the noise source and the receptor, be made of material with a surface density of at least 3 lbs per sq ft, have a minimum STC rating of STC-30 according to ASTM Test Method E90, and be free of gaps or holes. When barrier units are joined together, the mating surfaces of the barrier sides shall be flush with each other. Gaps between barrier units, and between the bottom edge of the barrier panels and the ground, shall be closed with material that completely closes the gaps and is dense enough to attenuate noise.

Figure 4.4. Sample barrier specification.

Figure 4.4 shows an example of a noise barrier specification.

Acoustical Curtains. Acoustical curtains are commercially-available mass-loaded heavy vinyl quilts that can reduce sound levels by about 5 to 10 decibels. Curtains are typically installed in vertical segments. All seams and joints should have a minimum overlap of 2 in. and be tightly sealed (e.g., with Velcro strips or wire ties).

Figure 4.5 shows an example of an acoustical curtain specification.

Receptor Control

When all other approaches to noise control have been insufficient, control efforts at the receiver should be undertaken. It should be remembered that the critical receiver might not be human. Certain precision equipment or interior building space can require very low levels of ambient noise and vibration.

Receptor Mitigation Techniques

Receptor problems usually involve individuals located very close to the noise-generating activity, in which case it may be more effective to improve the individual's acoustic environment rather than controlling all emitted noise.

Window Treatments. In general, window openings are the weak link in a structure's external façade, allowing noise infiltration into the building. A good acoustical window treatment, such as interior or exterior storm sashes, can provide an incremental noise reduction improvement (beyond that provided by the original window) of 10 decibels within a building. Therefore, an acoustically-treated window, or a new triple-glazed acoustical window, for example, can provide a total outside-to-inside noise reduction of 35 decibels or more.

Tip

Window treatments are most cost effective when a relatively few or a widely-scattered number of receptors require noise mitigation.

> The acoustical material shall be weather- and abuse-resistant and exhibit superior hanging and tear strength during construction. The material shall have a minimum breaking strength of 120 lbs per in. per FTMS 191 A-M5102 and minimum tear strength of 30 lbs per in. per ASTM D117. Based on the same test procedures, the absorptive material facing shall have a minimum breaking strength of 100 lbs per in. and minimum tear strength of 7 lbs per in.
>
> The acoustical material shall have an STC of STC-25 or greater, based on certified sound transmission loss data taken according to ASTM Test Method E90. It shall also have a Noise Reduction Coefficient rating of NRC 0.70 or greater, based on certified sound absorption coefficient data taken according to ASTM Test Method C423.

Figure 4.5. Sample acoustical curtain specification (FTMS = Federal Test Method Standard).

The construction noise residential window treatment policy for the Central Artery/Tunnel (CA/T) project stated the following criteria to determine eligibility:

- The resident must be subjected to nighttime (10 p.m. to 7 a.m.) construction noise
- Other control methods (source and path) will not adequately mitigate the noise
- The resident must be in close proximity to the construction work
- The applicant must be a legal resident
- Construction noise levels at the residence must be exceeding the project's noise limits
- Elevated noise levels are forecasted to exist consistently for a period in excess of two consecutive months
- Situations must involve health condition, hardship, or severe impact (i.e., not financial means)
- Mitigation is limited to bedroom windows, unless a relevant health condition is documented
- There must be a written right-of-entry to authorize the work
- The CA/T Environmental Panel must approve the treatment and associated cost

Figure 4.6. Sample window treatment program eligibility policy (CA/T Project, Boston).

Figure 4.6 shows a sample window treatment program eligibility policy.

If a treatment was approved, the CA/T project in Boston issued a task order to a window contractor. After the work was performed, a post-noise assessment was conducted. The contractor was paid by CA/T after the resident signed off on the completed work.

Temporary Relocation. In very special cases, temporary relocation may be necessary. Relocation has been used in California during 24-hour work to repair earthquake-damaged highways, on one occasion in Utah on the I-15 project because of an individual's medical problem, on the TRansportation EXpansion (T-REX) project in Denver, Colorado, during weekend demolition of nine bridges, and in Massachusetts for four apartments very close to the CA/T project.

Temporary relocation usually involves assisting affected residents, including those who might be frail or elderly, to move into a hotel for a few days or weeks while excessively loud work is being completed.

Vibration

Similar to sound, vibration is fluctuating energy in motion, through solid media rather than air. Humans and animals can be sensitive to vibration, particularly in the low-frequency range of about 1 Hz to 100 Hz.

Many types of construction activities cause vibrations that spread through the ground (ground-borne), most notably pile driving, hoe ram demolition, blasting, and vibratory compacting. Though the vibrations diminish in strength with distance from the source, they can produce annoying or objectionable audible and "feelable" levels in buildings very close to construction sites.

Rarely do vibrations reach levels that cause structural damage to buildings. However, minor cosmetic damages can occur at lower vibration levels and, in the case of old, fragile, or historical buildings, a danger of significant structural damage always exists.

Laboratory devices, such as electron microscopes and lasers, can be very sensitive to vibrations. Vibration displacement amplitudes of as little as 1×10^{-6} in. (1 micro-in.) can disrupt such sensitive equipment. Therefore, the area surrounding a construction site must be screened for research facilities, clinics, laboratories, and hospitals that might be using sensitive devices.

To control or limit project-caused vibrations, it may be necessary to place restraints on construction methods, allowable times, and equipment. However, the determination of acceptable vibration levels is very difficult because of its subjective nature with regard to being a nuisance.

It is the unpredictability and unusual nature of vibration, more than the level itself, that is likely to result in complaints. The effect of intrusion tends to be psychological rather than physiological and is more of a problem at night when occupants of buildings expect no unusual disturbance from external sources.

Vibration Sources and Strength

Vibrations from construction work are normally the result of blasting, impact pile driving, hoe ram demolition, drilling, or the use of vibratory rollers. Construction vibrations are generally assessed in terms of peak particle velocity (PPV) in units of in. per sec; however, they can also be expressed in vibration velocity decibel levels (VdB or Lv).

PPV vibration data based on measurement of construction equipment and operations have been published, as shown in Table 4.5. The table shows average source levels under a wide variety of construction activities. Resulting PPV levels measured or calculated at receptor locations, when compared against recommended criteria limits, can provide an indicator of the damage potential from the vibrations. Nevertheless, vibration levels below recommended criteria limits are not a guarantee that damage cannot occur or that complaints or claims will not result.

When vibration levels from an "unusual source" exceed the human threshold of perception (PPV, 0.008–0.012 inches per second (in./sec)), complaints may occur. In an urban situation, serious complaints are probable when PPV exceeds 0.12 in./sec (New 1990).

These levels are much less than what would result from slamming a door in a modern masonry building. People's tolerance will be improved provided that the origin of the vibrations is known in advance and no damage results.

A matrix of human response in relation to both blasting and earthquake motion is shown in Table 4.6. Note that humans are more sensitive to a blasting motion than an earthquake.

The Federal Transit Administration (FTA) also provides guidance on acceptable levels of construction vibration (Hanson et al. 2006). Structural categories are defined in FTA guidelines on

Table 4.5. Vibration levels for construction equipment and operations (Hanson et al. 2006).

Equipment		PPV at 25 ft (in./sec)	Approximate L_v[1] at 25 ft
Pile driver (impact)	upper range	1.518	112
	typical	0.644	104
Pile driver (sonic)	upper range	0.734	105
	typical	0.170	93
Clam shovel drop (slurry wall)		0.202	94
Hydromill (slurry wall)	in soil	0.008	66
	in rock	0.017	75
Vibratory roller		0.210	94
Hoe ram		0.089	87
Large bulldozer		0.089	87
Caisson drilling		0.089	87
Loaded trucks		0.076	86
Jackhammer		0.035	79
Small dozer		0.003	58

[1] RMS velocity in decibels (VdB) 1 micro-in./sec with an assumed crest factor (Peak/RMS) of x 4 (12 dB).

Table 4.6. Human response to motion (Oriard 1989).

Human Response	Earthquake (PPV in./sec)	Blasting (PPV in./sec)
Barely perceptible	0.26–0.80	0.01–0.10
Distinctly perceptible	0.46–1.40	0.05–0.50
Strongly perceptible	1.50–5.70	0.50–5.00

the basis of the sensitivity (or vulnerability) of buildings to major structural or minor cosmetic damages from vibration, as shown in Table 4.7.

Major structural damages are seldom a concern from construction activities and only occur when a building is exposed to intense shock from events such as blasting or pile driving within a few feet. Minor cosmetic damages are typically more of a concern from construction activities and can manifest in cracking of wall or ceiling plaster, exacerbating spalling cracks in brickwork, and rattling/breaking of windows and other fragile objects.

The criteria limits recommended by the FTA for avoidance of major or minor damages are expressed in units of PPV in in./sec. For major damages, a limit of 2.00 PPV is recommended. Different criteria limits, as shown in Table 4.7, are provided for minor cosmetic damages depending on the receptor's structural category and whether or not the source is transient (such as impact) or continuous in nature.

Sensitive Equipment Vibration Criteria (VC) Curves

Figure 4.7 shows a family of VC curves intended to protect sensitive devices from excessive vibration. These criteria originated with the Institute of Environmental Sciences and Technology (IEST) and were published in its Standards RP-CC012.2 and RP-CC024. The FTA subsequently adopted and recommended these criteria as well in their *Transit Noise and Vibration Impact Assessment Manual* (Hanson et al. 2006).

The FTA manual only shows VC curves down to VC-E (125 micro-in./sec or 42 VdB); however, the curves can be extended to lower VC-F and VC-G ranges. In general, each lower VC curve represents half the vibration velocity level of the one above it.

The VC curves elbow upward at and below the 8 Hz third-octave band; however, they should be extended linearly (flat) for particularly-sensitive devices whose mounting systems are not fully understood. Table 4.8 provides the vibration velocity levels for each VC curve expressed in engineering units and decibels, and a description for the intended use of each criterion curve.

Table 4.7. Federal Transit Administration construction vibration guidance (Hanson et al. 2006).

Building Category	PPV (in./sec)	Approximate L_v[1]
I. Reinforced-concrete, steel, or timber (no plaster)	0.50	102
II. Engineered concrete and masonry (no plaster)	0.30	98
III. Non-engineered timber and masonry buildings	0.20	94
IV. Buildings extremely susceptible to vibration damage	0.12	90

[1] RMS velocity in decibels (VdB) 1 micro-in./sec with an assumed crest factor (Peak/RMS) of x4 (12 dB).

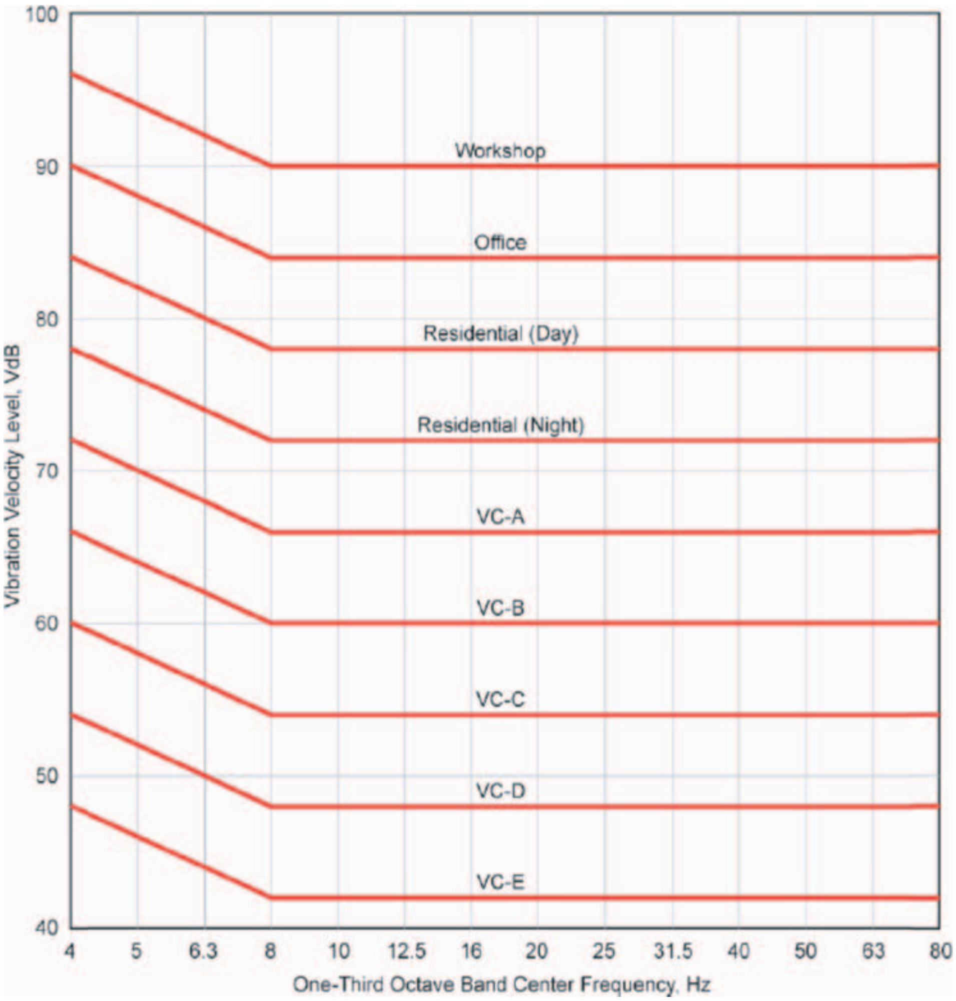


Figure 4.7. Impact assessment VC curves (Hanson et al. 2006).

Table 4.8. VC limits and intended use (Hanson et al. 2006).

VC Curve Name	Vibration Limit		Intended Use
	Micro-in./sec	VdB	
VC-A	2,000	66	Adequate for medium- to high-power optical microscopes (400X), microbalances, optical balances, and similar specialized equipment
VC-B	1,000	60	Adequate for high-power optical microscopes (1000X), inspection, and lithography equipment to three-micron line widths
VC-C	500	54	Appropriate for most lithography and inspection equipment to one-micron detail size
VC-D	250	48	Suitable in most instances for the most demanding equipment, including electron microscopes operating to the limits of their capability
VC-E	125	42	The most demanding criterion for extremely sensitive equipment

Vibration Mitigation

The mitigation techniques for decreasing vibration impacts are similar to those used to lessen noise nuisances. The following are the questions to address concerning vibrations:

- Will construction operations cause vibrations?
- Are sensitive populaces, buildings, structures, or laboratory equipment in the vicinity?
- Can site-specific trials be conducted to assess possible damage/intrusion?

Answering these questions requires a clear understanding of construction equipment location and construction processes in relation to critical receptors.

Tip

If the goal is to mitigate complaints, even from simply noticeable vibrations, the zone of concern can be as great as 1,300 ft.

Key Take-Away

If Damage/Intrusion is Possible, Modify Design and/or Construction Method

The basic approach with regard to contract specification control of vibration is the imposition of a limiting value for vibration. This is usually in terms of a resultant PPV at a specified distance or at a critical structure. Such a specified VC results in a sharing of risk with the contractor, so pre-construction photographic surveys should be conducted to document the buildings' existing conditions.

Specifications and Design

Establishing limitations on blasting and pile driving vibrations can be done by project specification. For example, impact pile driving can be replaced with hydraulic push piles, drilled caissons, or slurry walls; or blasting can be replaced with rock drilling and splitting. Typically, these alternate methods take more time and may cost more to accomplish, but they are available if/when vibration damages must be avoided.

In addition, specifications can be used to control vibration nuisance risks as outlined in Table 4.9.

Resource

The principal means of mitigating vibration problems, as reported by STAs, pile driving contractors, and engineering consultants, can be found in *NCHRP Synthesis of Highway Practice 253:*

Table 4.9. Effective vibration control specifications.

Category	Control Directives by Specification
Project layout and access	Route heavily loaded trucks away from residential streets. Establish designated haul routes so that the fewest possible residences are affected. Create project work zones that control the placement of operating equipment on the construction site so that equipment is kept as far as possible from vibration-sensitive receptors.
Sequence of operations	Phase demolition, earthmoving, and ground-impacting operations so they do not occur concurrently.
Community outreach	Whenever possible, perform high-vibration tasks at the least objectionable times of day as determined through dialog with the affected public.
Work hour restrictions	Limit vibration-causing activities to daytime hours, or daytime and evening hours only. People are more aware of vibration in their dwellings during late night and early morning hours.
Alternative construction methods	Drilled piles or the use of a hydraulic pushed or vibratory pile driver causes lower vibration levels where the geological conditions permit their use. Avoid impact pile driving whenever possible in vibration-sensitive areas.

Table 4.10. Dust control mitigation strategies by category (Schexnayder and Ernzen 1999).

Category	Countermeasures
Earthwork	Watering, pre-wet sites
Disturbed surface areas	Watering, chemical stabilizers, wind fences, wind screens, berms, stabilization with vegetation or gravel
Open storage stockpiles	Watering, chemical stabilizers, wind fences, wind screens, berms, coverings, enclosures
Unpaved roads	Watering, chemical stabilizers, stabilization with gravel, restrict vehicle speed
Paved road track out	Limit or restrict access; stabilized, gravel, or paved construction entrance pad; wheel-wash station; vacuum/wet-broom public roadway
Hauling	Maintain minimum freeboard, tarp
Demolition	Watering, pre-wetting
Work limits during high winds	Cease work temporarily on hot dry nights or for certain wind directions

Dynamic Effects of Pile Installations on Adjacent Structures. TRB, National Research Council, Washington, D.C. (Woods 1997).

Key Take-Away

Vibrations typically do not occur at the same moment; therefore, the single highest vibration-producing source will create the critical PPV level.

Dust

During the night, many households leave their windows open to take advantage of the cool night air. With urban nighttime construction projects being very close to people's living space, dust can be a problem.

Nighttime construction dust problems are accentuated by the lighting, which makes the particulate matter very visible. Fugitive dust may be generated by construction operations, and the contract specifications should require that the contractor prepare a dust control plan.

In many cases, dust control is not a problem that is limited to nighttime activities; therefore, air quality/dust control plans should be for all hours of the day or night. Specific areas that dust control plans should address are outlined in Table 4.10.

Summary

Good construction noise, vibration, and dust control specifications are effective tools in mitigating the adverse and objectionable impacts of construction on abutting communities.

The primary goal with potential nighttime construction nuisances is to minimize the impact of construction noise at night when people are most sensitive. The mechanisms to achieve that goal vary from contract to contract because of area-specific conditions, the type of construction, the inherent noise reduction qualities or sensitivity of affected receptor structures, the desires of the affected abutters, and the cost and schedule implications of mitigation. In addition, it may be necessary to have specific noise mitigation measures specified for certain work.

CHAPTER 5

Productivity

The productivity of construction operations has many definitions that range from how effective and safe workers are on the job to exact metrics of how many units of a construction product are accomplished in a certain span of time. The definition that is most widely acceptable is the one that focuses on units produced over a defined time duration, or focuses, conversely, on the labor hours needed to produce a unit.

Perceptions vary concerning the degree that construction productivity is impacted by working at night. Some judge worker performance as a key factor that can cause decreased nighttime productivity. Other studies cite less traffic congestion as a major contributor to productivity improvement during nighttime shifts. Strong evidence from research studies shows that productivity for many activities is not impacted by nighttime construction operations.

Key Take-Away

Opinions are contradictory as to whether construction productivity is affected by working at night. Contrary to intuitive beliefs, productivity during nighttime operations may not be affected. This can be attributed to two factors counteracting yet balancing each other. While an expected loss in worker productivity at night might be expected, in many cases, improved work conditions have been found during nighttime hours.

STAs need to be sure to consider productivity and production rates, similar to contractors, when developing project phasing and estimating project time and cost.

Productivity Study Findings

Numerous studies have found no difference in nighttime versus daytime production rates. Studies by Ellis et al. (1993), Dunston et al. (2000), and Colbert (2003) on pavement milling and asphalt paving recorded no difference between day and night shifts in productivity rates.

The Ellis et al. (1993) study also reported that the work costs less when conducted at night. Douglas and Park's (2003) study using 124 datasets from asphalt paving projects found 23 percent more tonnage placed per hour at night than during the day. Lee's (1969) study on concrete paving reported a productivity increase of 1.5 lane-miles per night. Higher productivity levels are attributed to longer working hours and less interference of traffic at night (Elrahman 2008).

Key Take-Away

The NYSDOT in 2008 found no difference in productivity levels between night and daytime operations. Higher productivity levels at night may be experienced, though, because of less interference from traffic and longer working hours (Elrahman 2008).

Factors Impacting Nighttime Productivity

Factors that have a potential impact on nighttime productivity can be grouped into two main classes: human and work environment. Human factors deal with the impact that nighttime work has on construction laborers and supervisors, and work environment deals with issues such as nighttime traffic, availability of support services, and weather impacts. Specific conditions under each class may have either a positive or negative impact on nighttime work productivity.

Human Factors

Transportation projects have work schedules that require employees to be on site for extended periods of time, frequently during evenings and nights, as well as on weekends. The nature of the work affects worker fatigue through three main pathways: number of hours at work, timing of shift schedule, and task-specific demands of the work (McCallum et al. 2010).

Duration and timing of work operations can affect fatigue and loss of productivity primarily through sleep loss, which can result from curtailed opportunity for sleep under some work schedules. The third pathway is related to task-specific effects. While extensive scientific literature exists exploring the relationship between fatigue and adverse outcomes in occupational and transportation settings, most occupational work studies have not looked specifically at worker productivity. Most work studies have instead examined work schedule as a precondition for fatigue and tried to quantify a relationship to adverse outcomes such as error, injury, and death.

A limited number of studies have evaluated the impact of extended overtime and shift work on labor productivity. These studies have shown that productivity decreases as the number of working hours per week increases. Hanna et al. (2005) focused on labor-intensive activities such as electrical and mechanical work. Overtime in this study was considered to be any work performed in addition to the typical 40 hours scheduled per week.

Key Take-Away

Extended periods of overtime have a long-term impact on labor productivity.

The effect on productivity is also dependent on whether the night work is a constant work-shift assignment, meaning that laborers are always assigned to work at night, or a periodic alternation between shifts based on job requirements or rotating day/night shifts. These two dissimilar situations have different impacts on sleep recovery opportunity and circadian rhythm adaptation affecting work productivity (Daan et al. 1984).

The circadian process is a 24-hour rhythm produced by the human biological clock. It promotes wakefulness during the day and sleepiness during the night, making staying awake through the night a challenge even when managing to get enough sleep beforehand.

Fatigue is regulated by the circadian process as a function of time of day. Moreover, the circadian process makes it difficult to get enough sleep during the day, especially during the "wake maintenance zone" in the early evening (Dijk and Czeisler 1994).

Circadian patterns have a number of physiological symptoms that affect human performance. As such, fatigue and performance in the workplace is a function of both time awake (due to hours of work) and time of day (due to the work shift) (Åkerstedt 2007), plus the nature of the work. Therefore, circadian patterns of human performance may influence nighttime construction activities in terms of labor productivity (Goel et al. 2011).

Most of the data on circadian effects were obtained in laboratory settings where it is possible to control sleep time and measure performance precisely. In controlled settings, it is clear that sleep deprivation results in dose-response relationships, with greater sleep deprivation leading to larger performance decrements, and that these effects are cumulative, so that the longer a subject is sleep-deprived, the greater the effect (Van Dongen et al. 2003). However, the relationship of laboratory findings to operational settings, while indicative of how sleep has an impact on performance, is far from being direct.

One study that evaluated the impact of circadian patterns asked subjects to perform a range of tasks every 2 hours to estimate the magnitude of the endogenous and exogenous components of the subject's circadian pattern. Performance during the different phases of the circadian cycle was found to be considerably different with respect to the different tasks performed (Folkard et al. 1993). The results indicate that performance of tasks may adjust at varying rates, which means that shift timing and operations need to be adjusted according to the type of work task.

Key Take-Away

The circadian process is a 24-hour rhythm produced by the human biological clock. It promotes wakefulness during the day and sleepiness during the night, making staying awake through the night a challenge even if the worker manages to get enough sleep beforehand. Circadian cycles have an impact on human physical and mental performance.

Key Take-Away

Circadian patterns have different impacts on physically active versus inactive people. Physically active people (like construction workers) exhibit troughs in their performance during the early morning but have twice the performance of physically-inactive people. People who prefer working at night have improved performance on tasks as the evening progresses, while morning-preferring people have declining performance when working in the evening.

Tip

Workers should be allowed flexibility in choosing their work shift. Night-preferring workers should perform better at night, while morning-preferring people will perform better during the day. Using a monetary incentive may cause workers to change their preference but not necessarily change their performance. Early mornings should be reserved for less-intense work due to the decreased performance of physically active workers during this period.

The general trend in sleep research suggests the best way to address the problem of fatigue and performance in operational settings is with an integrated approach. This is because no single measure or intervention is likely to be particularly effective. Improved performance requires a combination of the following (Rosekind et al. 2006 and Caldwell et al. 2008):

- Work hour controls.
- Training and education.
- Scheduled risk assessment.
- Healthy sleep and fatigue countermeasures.

Caldwell et al. (2008) delineated the principal strategies for managing alertness in operational contexts. The first element, and arguably the most important, is that management and staff understand the nature of fatigue. The tendency has been to think of fatigue simply as a state of mind that can be overcome with "professionalism" or "endurance." Such philosophies lead to undesirable results in terms of productivity and safety.

Therefore, establishing an understanding about the physiological basis of fatigue, how it manifests in work situations, and what can be done about it, are the key components of a training and education program to improve nighttime productivity and safety. A variety of materials are available to create programs, such as the *Fatigue Management Reference,* developed by the U.S. DOT Human Factors Coordinating Committee (McCallum et al. 2003).

Resource

Commercial Transportation Operator Fatigue Management Reference: http://www.fra.dot.gov/downloads/research/fatigue_management.pdf

Tip

The hours of least alertness are between 1 a.m. and 6 a.m. (Moore-Ede et al. 1989). Therefore, in the design of nighttime operations, tasks requiring high levels of skill and alertness should be avoided during these hours. If skill-intensive tasks are to be performed during these hours, special attention should be given to quality control to avoid productivity disruptions caused by rework.

The Caldwell et al. (2008) report also provides strategies for improving work/rest scheduling, techniques for optimizing sleep, and techniques for temporarily mitigating fatigue (countermeasures).

Work-Zone Factors

Work-zone factors affecting productivity include lighting and visibility, traffic controls, and roadway and traffic conditions. If the work zone is dimly lit and quiet, productivity will probably suffer. These factors are discussed in detail in Chapter 3, Illumination, and Chapter 8, Safety.

Light exposure affects the timing of the circadian process. Brighter light is more effective at shifting the circadian rhythm, but the timing of light exposure is also critical in determining the degree of shifting and even the direction of shifting (Duffy and Czeisler 2009). Exposure to light in the late evening delays circadian rhythms. Consequently, lighting for nighttime work is necessary both for visibility, to perform the actual work, and in terms of the workforce's ability to resist fatigue and remain productive.

Tip

Planned light exposure patterns are helpful in managing the circadian process and mitigating fatigue (Lee et al. 2006).

Work Management Countermeasures

Work management fatigue countermeasures can decrease the risk of adverse productivity outcomes. Measures to maintain productivity require close management attention to the work environment and tasks.

Key Take-Away

Of primary importance is the ability of the workforce to gain adequate sleep; therefore, work schedules should provide a minimum of 10 hours off between shifts.

Tip

Project-site interventions that can be used include the following:

- Caffeine.
- Naps (Miro et al. 2003).

(Tip continued next page)

- Physical activity to improve physiological alertness (Atkinson et al. 1993).
- Breaks to reduce cognitive, time-on-task fatigue (Moore-Ede et al. 1989).

Management should institute safety training about fatigue, design work schedules to provide adequate rest for workers, and make work-zone improvements that decrease worker fatigue or anticipate likely fatigue problems (e.g., stepping into traffic and encounters with heavy equipment).

In planning nighttime work activities, management needs to think in terms of the physical and cognitive demands of work tasks. This can be a paradigm shift in how work is accomplished and breaks are scheduled.

Tip

A good practice is to have personnel move around or change tasks during a night shift.

While standard practice is to design work zones primarily to accommodate the traveling public, nighttime construction requires a fatigue-sensitive work zone that can necessitate positive physical barriers between the workers and the traffic. This requirement can change how tasks are performed compared to normal daytime practice.

Tip

Methods for managing fatigue and improving productivity during nighttime construction include the following:

- Risk assessment and work activity modification.
- Training, awareness.
- Rest breaks, possibly even nap areas.
- Physical activity.
- Work-zone setup (bright light is effective).
- Caffeine—the most widely used operational countermeasure for fatigue.

Resource

Fatigue Resource Directory, which was established by the Fatigue Countermeasures Group at the National Aeronautics and Space Administration (NASA) Ames Research Center, is available online at http://human-factors.arc.nasa.gov/zteam/.

Productivity Measurement Techniques

The productivity of nighttime construction operations requires good management techniques. Therefore, the following section discusses methods for productivity measure and modeling.

Productivity Measurement

The focus of many construction improvement programs is the acquisition of accurate and consistent labor productivity data. The quality of the data collected by these exercises usually depends on the data collection effort. There are many data sources, including historical records and previous productivity studies.

The difficulty that most methods suffer from is a lack of consistency in the way they are performed. Noor (1998) critiqued and analyzed existing productivity measurement methods to develop practical and cost-effective productivity data collection methods that lead to consistent and accurate productivity data. Common productivity measurement techniques include those outlined in Table 5.1.

Table 5.1. Common productivity measurement techniques (Noor 1998).

Technique	Method Notes
Direct observation	Continuous observation relies on a trained observer monitoring construction operations throughout the shift. The main shortcoming of this technique is that a single observer can monitor only a single crew with a predetermined maximum size.
Work study	Direct monitoring does not need to be for the entire day. Instead, the monitoring period corresponds to the length of the work cycle of the operation monitored.
Audio-Visual	Audio-visual techniques such as time-lapse photography and videography using movie and video cameras are used to acquire data. The advantage of audio-visual techniques is that they decrease the burden of data collection and create a permanent record of the activities.
Activity sampling	This technique consists of making observations of workers on a periodic basis. It relies on a snapshot of the activity being performed and the workers being studied.

Productivity measurements on transportation construction projects usually rely on records of materials and equipment usage. Labor productivity is rarely measured and recorded. This is partly due to the equipment-intensive nature of these projects.

Tip

Productivity measurement can be performed on a discrete or continuous basis. A strong correlation exists between the cost to obtain data and reliability of the data. The higher the reliability, the greater the costs to collect the data.

Key Take-Away

A wide variety of techniques can be used to measure labor productivity. The selection of the technique should consider reliability and cost. A midrange technique (such as activity sampling) requiring few measurements on multiple occasions during the work week is advised.

Tip

Analyses of productivity data can help define problems causing loss of efficiency on a project. Analyses can show the impact of factors on project progress, and can help in developing strategies to mitigate their effects. These analyses are neither difficult nor time consuming to perform using modern computer software and video equipment.

Productivity Modeling Methods

The data collected through productivity measurement efforts can be used to predict and estimate productivity.

One interesting study by Boddy et al. (1986) demonstrated, in some instances, no systematic relationship between wages and labor productivity. Another important finding was that wages are related to productivity in the regular shifts but not during overtime periods. The study demonstrated that given a fixed crew size, productivity is more a function of downtime than relative wages.

Key Take-Away

Work-shift productivity was found to correlate more to the amount of downtime on a particular shift. Therefore, higher nighttime wages may not cause an increase in productivity. Management policy should focus on work planning to achieve continuity at night rather than on monetary incentives.

Productivity Improvement

Studies have indicated consistently that these are the priority areas for construction productivity (Arditi 1985):

- Planning and scheduling.
- Labor management relations.
- Site supervision.
- Equipment policy.
- Engineering design.

The California Department of Transportation (Caltrans) has had several urban freeway rehabilitation projects that required around-the-clock construction operation to minimize the impact they had on motorists. These projects have provided data for evaluating productivity rates (Lee et al. 2007).

The productivity studies investigated different lane-closure schemes and rehabilitation strategies. The results showed production rates and learning-curve effect were higher in cases where the roadbed was fully-closed and full lane widths rehabilitated compared to cases of partial closure and partial-width rehabilitation. Continuous slab replacement had a higher production rate and learning-curve effect than random slab replacements.

These results imply that specified construction sequencing and phasing affect productivity. The study findings were unable to discern affirmatively the impact of nighttime activities alone on construction operations. Lee et al. used Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS) to perform the analyses.

Resource

The CA4PRS software identifies optimal project work strategies that balance the construction schedule with inconvenience to drivers and transportation agency costs. It is a versatile tool for analyzing the productivity effects of specified work sequences: http://www.fhwa.dot.gov/research/deployment/ca4prs.cfm

Productivity and Production Rates

Various STAs have published production rates for important construction activities. Establishing and adapting these rates is governed mostly by the FHWA guide for determination of construction contract time. While STAs have developed such productivity information, little guidance, specifically about nighttime construction production rates, is available.

Resource

The FHWA *Guide for Construction Contract Time Determination Procedures* is a valuable resource: http://www.fhwa.dot.gov/construction/contracts/t508015.cfm

Most of the published STA data are overall production rates for an activity or pay item; this should be distinguished from labor, equipment, or crew productivity rates. In a sense, the published production rates are an aggregation of the combined productivity of labor, equipment, or crews used to perform the work.

STAs collect production-rate data based on historic data found in inspection reports, which are not usually concerned with how effective contractor laborers are in performing the work. Productivity rates, on the other hand, describe the number of units of output that could be produced on a specific activity (such as concrete paving) by individual laborers (such as concrete finishers), equipment (such as the concrete paver), or crews (which are the combination of a specific piece of equipment and the labor needed to operate it).

Detailed productivity rates for most labor, equipment, and crews can be found in the RSMeans construction cost data references.

Key Take-Away

Productivity versus Production Rates

Productivity rates look at production per unit time of individual labor, equipment, or crews, while production rates published by STAs are overall rates of production for activities or pay items. Productivity rates provide more detailed information than overall production rates.

Tip

STAs usually have good data describing the labor, equipment, and crews used on projects, as well as their corresponding production. STAs can therefore establish nighttime productivity rates of labor, equipment, and crews similar to the daytime rates already produced.

Illinois Department of Transportation (IDOT) Production Rates

The IDOT *Bureau of Design and Environment Manual* lists production rates for major items (IDOT 2010). These rates are based on an average 8-hour work day. The manual states that the published rates should be reviewed periodically to adjust the rate for advancements in equipment outputs or construction techniques.

The IDOT manual provides a low and a high value for the production rate of each item. The low rates are for small projects, while the high rates are for larger projects. Expedited projects need the published rates to be adjusted for longer working days, but the manual does not provide a method for making such an adjustment.

Finally, the manual explains that rates much higher than those published could be achieved in particular situations. Again, there are no production rates specifically for nighttime work.

Michigan Department of Transportation (MDOT) Production Rates

Similar to Illinois, MDOT utilizes production rates published in its *Construction Manual* for calculating the overall contraction duration of projects. The origin of the published rates and their data is described.

MDOT does maintain an accurate database of production records in a software system called *Field Manager,* which stores construction inspection records (Mattila and Dina 2003). Similar records of actual production records may be available at other STAs; however, an important factor to consider is that these records need to include information about production-impacting factors such as project location, weather conditions, equipment and construction methods, size of job, and worker skill.

Summary

The main interacting elements that control nighttime work productivity are human factors, work-zone factors, and work management countermeasures. Human factors are mainly the effects of worker fatigue through three main pathways: number of hours at work, timing of shift schedule, and task-specific demands of the work. These factors are controlled largely by the circadian process—human physiological rhythms and cycles.

Work-zone factors, on the other hand, are the physical conditions, and primarily the lighting.

Finally, work management countermeasures are the methods of on-site intervention that ensure worker safety and productivity, including the use of caffeine and naps to improve physiological alertness.

Specific techniques are available to improve nighttime work productivity. These techniques include good lighting, planning and scheduling, labor management relations, and site supervision. The CA4PRS software is a good tool that identifies strategies to balance the construction schedule with inconvenience to drivers and transportation agency costs.

CHAPTER 6

Quality

The most important advantage of nighttime construction and why it is used in most cases is to reduce congestion and delay for the traveling public during project construction. At the same time, it is essential for STAs to maintain the quality of nighttime construction operations parallel with the FHWA national objectives on quality construction, which are to improve system performance; decrease congestion and impacts on the environment; improve safety by minimizing work-zone frequency, duration, and disruption of traffic flow; and improve the economic efficiency of highway investments.

Many activities can be performed during nighttime construction, with road paving being the most common. According to research conducted by the National Quality Initiative (now the National Partnership for Highway Quality), pavement smoothness is one of the most significant measures used to judge the quality of the roads. This research has resulted in development of several quality programs, such as the FHWA HIgh PERformance Concrete PAVing (HIPERPAV) program, to ensure that quality in highway and road construction is met in terms of long-term performance expectations with the fewest maintenance and rehabilitation requirements.

In addition, resources such as FHWA's National Highway Specifications provide the framework for construction project evaluation and assessment, from the quality of materials to the final pavement smoothness (https://fhwapap04.fhwa.dot.gov/nhswp/).

Al-Kaisy and Nassar (2003) surveyed STAs and IDOT districts. The results showed that 60 percent of the STAs having experience with nighttime construction believe night work had no impact on quality and five percent believe it actually resulted in better quality. As far as the Illinois DOT districts with nighttime construction experience, 88 percent reported that the quality of work at night was equal to or better than work completed during daylight hours.

Key Take-Away

"Quality of work does not seem to be affected by performing work at night" (Elrahman 2008).

Studies on the quality of work produced at night versus during the day do not confirm the perception that the quality of nighttime work decreases. Price (1985) concluded that the quality of work does not experience significant degradation if the work was performed at night versus daytime. Hancher and Taylor (2000) and Al-Kaisy and Nassar (2002) concluded that cooler temperatures at night and longer working hours can actually increase nighttime work quality. Park et al. (2001) reported that the International Roughness Index (IRI) scores for paving operations were only 3 percent less at night than during the day.

As more construction work is completed at night, it is important for transportation officials to understand and implement quality measures in nighttime construction. The following sections describe factors affecting nighttime construction quality inspections, quality of construction work at night, nighttime paving quality, and quality management programs adopted by agencies to maintain the quality aspect in nighttime work.

Factors Affecting Nighttime Construction Quality

This project's survey of 14 STAs found the perception to be that some factors may increase quality, while others may reduce quality (see Table 6.1). However, some activities may benefit from a factor, while the factor may detract from others. The requirements for each task should be considered.

Tip

Adequate visibility and proper temperatures are required to produce quality nighttime asphalt paving.

Nighttime work benefits from the low traffic volumes and cooler temperatures. Other important factors that have an impact on nighttime construction quality are as follows:

- Inadequate lighting and poor vision.
- Human factors.
- Insufficient amount of inspection and supervision.

Inadequate Lighting and Poor Vision

Conducting nighttime work is challenging, especially with visibility as one of the issues. Work quality is highly dependent on the ability to see the work. Therefore, sufficient lighting of the work area is important for quality and safety. With sufficient lighting, the final outcomes of the project produce similar quality to daytime work.

Each of the activities, when performed at night, may have its own visual requirement. Nighttime activities, such as painting spots on pavement by marking machine operators, may require a higher visual requirement compared to activities such as spotting string lines by workers (Hyari and El-Rayes 2006b).

Table 6.1. STA survey results on perception of factor impacts on quality.

Factor	Reduce Quality (%)	Same Quality (%)	Increase Quality (%)
Cooler temperature at night	50	36	14
Longer work hours at night	7	79	14
Lighting	86	14	0
Less interference of traffic	0	21	79
Quicker material deliveries	7	21	72
Allows more lanes to be closed	0	36	64
Increase duration of closed lanes	0	43	57
Effective communications among agency personnel, contract manager, and field staff	43	36	21
Availability and supply of materials and spare parts	57	36	7

Human Factors

Nighttime workers often experience fatigue due to lack of sleep/rest, as well as issues adjusting to the idea of working at night. Fatigued workers may be unable to stay mentally alert and focus on their jobs.

Insufficient Amount of Inspection and Supervision

It is necessary to provide good supervision on nighttime construction activities. Good supervision ensures that end products meet the specifications and standards, even though the work is conducted at night. In addition, inspectors should keep in mind the reflections made by lighting on asphalt pavement, as it greatly magnifies ridges and depressions.

The Quality of Construction Work at Night

Different types of construction and maintenance work are usually performed at night. In *NCHRP Report 498,* Ellis et al. (2003) concluded that nighttime highway work can be performed safely and with a level of quality and economy comparable to that achieved from daytime construction. The specifics tasks reviewed in that study are listed in Table 6.2.

Some activities, such as bridge deck overlays, may be better suited for nighttime work and do not suffer in quality when performed at night. During the summer months, cooler temperatures at night help to enhance the quality of the concrete placement. Achieving a good concrete placement during the day can be difficult due to the high temperatures or direct sunlight, because they speed up evaporation and the setting of portland cement concrete. For instance, placing latex-modified concrete on bridge decks is considered a very suitable task to be performed during nighttime construction.

Table 6.2. Highway maintenance and construction tasks performed at night (Ellis et al. 2003).

Maintenance Task Performed at Night	Construction Task Performed at Night
Maintenance of earthwork/embankment	Excavation—regular, lateral ditch, channel
Reworking shoulders	Embankment, filling, compaction
Barrier wall or traffic separator	Barrier wall or traffic separator
Milling and removal	Milling and removal
Resurfacing	Resurfacing
Repair of concrete pavement	Concrete pavement
Crack filling	Subgrade stabilization and construction
Pot filling	Base courses—clay, cement, asphalt
Surface treatment	Surface treatment
Waterproofing/sealing	Waterproofing/sealing
Sidewalk repair and maintenance	Sidewalk construction
Riprap maintenance	Riprap placement
Resetting guardrail/fencing	Guardrail fencing
Painting stripes/pavement markers	Painting stripes/pavement markers/metal buttons
Landscaping/grassing/sodding	Landscaping/grassing/sodding
Highway signing for maintenance works	Highway signing for construction
Traffic signal maintenance	Traffic signal construction
Highway lighting system repair and maintenance	Highway lighting system construction
Bridge deck rehabilitation and maintenance	Bridge deck construction
Damaged structures maintenance and rehabilitation	Drainage structures, culverts, and sewers construction
Sweeping and cleanup	Construction of other concrete structures

Nighttime Paving Quality

Studies by Hinze and Carlisle (1990a and 1990b) and Ellis and Kumar (1993) found that the quality of paving performed at night met smoothness specifications but can be less when compared to the quality of daytime paving. The Hinze and Carlisle study was based on questionnaires and not on actual project data.

A Washington State Department of Transportation (WSDOT) project, on which a statistical analysis of the Profile Ride Index (PRI) (measured in mm/km or in./mi) was performed, revealed no differences between daytime and nighttime paving shift smoothness (Dunston et al. 2000).

The contractor needs to exercise extra care and quality control when performing nighttime paving to ensure reasonable smoothness. Several methods are considered the most suitable to compare daytime versus nighttime paving quality. According to Douglas and Park (2003), the three methods used by the Oregon Department of Transportation (ODOT) are IRI, Composite Pay Factor (CPF), and Overall Condition Index (OCI).

- IRI "measures longitudinal pavement profiles to evaluate pavement condition and remaining life."
- CPF is used to "measure, through statistical analysis, the quality of the material that contractors produce and use during paving; resulting in the anticipated performance and quality of the pavement."
- OCI measures the pavement condition such as the amount of rutting, cracking, raveling, and bleeding present on pavements.

Asphalt compaction is another construction activity during which quality can be affected at night. The effect of nighttime on compaction, however, is less significant than on surface smoothness. Compaction test results from a daytime paving project, I-70 in Colorado, were compared to those of a similar construction job done during nighttime hours on I-25 (Price 1986a and 1986b).

It was felt initially that compaction performance might suffer due to cooler nighttime temperatures. However, compaction of night paving was just as high as that of day jobs and, in some tests, it was even higher. The overall quality of the work done on the nighttime project was very similar to a well-done day job (Rebholz et al. 2004).

Paving at night can improve quality, primarily because material is delivered at a steady rate given the following:

- Better production at night.
- Less traffic to and from the jobsite.
- Less interference from outside.
- Less congestion at the plant when loading trucks.
- Trucks have better turnaround time.
- Rush-hour traffic avoided, morning and evening.

The common perception among contractors, owners, and state officials is that the quality of nighttime asphalt paving, either repairs or overlays, obtained by using proper procedures, adequate inspection and testing, and strict grade control, compares favorably with the quality of the overlays constructed during daytime (Rebholz et al. 2004).

Key Take-Away

Of the 32 projects in 1998 that won National Asphalt Pavement Association Quality in Construction Awards, the majority, whether rehabilitation or new construction, involved night paving, restricted hours, or phased construction to limit disruption of traffic flow.

Quality Management Programs

Most studies conducted indicate the quality of the finished product done under nighttime operations has not been significantly different from work performed during the daytime (Elrahman 2008). Regardless, contractors and agencies still need to exercise good quality management programs during nighttime construction.

One of the most recommended and frequent practices is scheduled inspections. None of the agencies interviewed for this study indicated that the quality expectations were any different, or lower, for work performed at night.

Similar to daytime construction, adequate inspection needs to be conducted to obtain quality work at night. Quality inspection may be conducted frequently or not, but the work/task needs to be monitored continuously. The inspection may be performed by the agency or its representative.

Either way, it is necessary to ensure that adequate inspection is available by determining the need and frequency of the inspections, as well as the staff needed to perform the inspections. Advance planning is essential to ensure adequate inspectors are available for staffing nighttime projects.

In addition to inspection of the work, the equipment used in nighttime construction should be inspected on a regular basis. Any devices that are dirty or impaired and result in low visibility compared to visibility with good-condition devices should be replaced immediately. Equipment inspection can be performed regularly prior to the start of nighttime work to avoid problems.

Nighttime asphalt paving inspection challenges include the following:

- Road alignment.
- Mix issues, such as segregation.
- Mix temperature—lumps.
- Truck beds not clean—cannot see until too late.
- Sampling mix is more difficult due to lighting—cannot see mix as well.

Tip

Be sure to inspect the devices used for nighttime work, as they might be satisfactory for daytime use but not nighttime because of inadequate visibility under headlamp illumination at night.

Tip

Maintain qualified inspection staff that are available for night reassignment on short notice to fill in as needed.

Resource

The American Traffic Safety Services Association (ATSSA) has a Comprehensive Inspection Training course on CD-ROM and offers a companion product to the training titled *Quality Guidelines for Work Zone Traffic Control Devices.*

http://www.atssa.com/LinkClick.aspx?fileticket=zXPoddZMiD0%3D&tabid=64

Conclusions

Most agencies report that nighttime construction quality is equal to or better than daytime work. A review of previous studies also makes it clear that the quality of nighttime construction projects is comparable to that of daytime projects. One of the main reasons is that both daytime and nighttime projects have the same quality specifications, regardless of when the work is performed.

However, lack of good lighting when conducting nighttime work may result in poorer work quality because work quality is highly dependent on the ability to see the work. Therefore, it is very important for transportation agencies to ensure sufficient lighting is in place when performing nighttime construction and inspecting the work.

The need to maintain visibility should be discussed during pre-bid or pre-operation meetings. In addition, it is recommended that the quality assurance program for nighttime construction, such as scheduled inspection, be developed and implemented as needed to evaluate the overall quality and effectiveness of nighttime construction tasks. Consequently, the program also helps to identify areas in which improvement is needed to ensure that the quality specification of a task can be met.

CHAPTER 7

Cost

A significant concern and perceived disadvantage of nighttime construction is that construction costs are higher. However, a careful review of past studies of nighttime construction costs indicates that, while in certain circumstances costs are higher, in most cases, nighttime construction costs are comparable or even less than those experienced with daytime work.

A study sponsored by FDOT using bid item cost comparisons found no cost differential on individual items, and the study noted that the total program cost was less for work at night than for work during the day (Ellis and Kumar 1993). While high-cost item variations were found between the projects, standard deviation measurements showed the unit costs were more dependent on project-related conditions than on changes for nighttime or daytime work (Rebholz et al. 2004).

The study did not include an analysis of competition for the work, so it is difficult to identify specifically why the total project cost was lower. Ellis and his team of researchers completed several other studies of nighttime construction, and their final conclusions were that cost, quality, and productivity are not significantly different between daytime and nighttime operations (Ellis et al. 1991 and 1993).

A study by Hinze and Carlisle (1990a) did find that "contract" costs were 9 percent higher for night work because of increased costs associated with the following:

- Augmenting traffic control.
- Need for lighting.
- Worker overtime or premium pay.

Key Take-Away

For most projects, the cost of work items is not dependent on whether the work is performed during the day or at night. Project-specific conditions are the drivers that cause price differentials between daytime and nighttime work.

Additional costs were sometimes incurred because of material delivery at special times, inspection, and operating concrete and asphalt plants beyond the normal work day. These potential additional costs are a clear indicator that STAs should carefully consider the requirements for nighttime traffic control and lighting.

The contract cost increase will be greater for small projects where the overhead cost of lighting and traffic control must be spread over fewer bid items. Despite the increased costs for traffic control and lighting work items, road user costs experienced by the public are typically reduced when work is performed at night. In addition, lower nighttime traffic volumes can result in convenient and faster delivery of materials to the jobsite and transport of waste from the site, potentially reducing the overall project cost.

In summarizing the situation, the Transportation Research and Development Bureau of the NYSDOT concluded the following (Elrahman 2008):

- ***User cost*** decreases when work is performed at night because of the elimination of delays—businesses experience less disruption as well.
- There is no consensus on whether ***construction costs*** increase or decrease as a result of performing work at night. This seems to be dependent on project size and specific work operations.

Key Take-Away

Work Tasks Affect Costs

Even with good lighting, lifting operations are very difficult at night. At about 15 ft above the operator's location, objects disappear into the dark sky. The contractor for the Woodrow Wilson Memorial Bridge widening in the early 1980s is of the opinion that the nighttime crane work led to significantly reduced productivity and increased costs.

The following sections of this chapter address the factors that influence nighttime construction costs, considerations in estimating nighttime costs, analysis of nighttime costs compared to daytime costs, and best practices in minimizing nighttime construction costs.

Factors Influencing Nighttime Costs

Little consensus exists among transportation personnel or between agencies on the specifics of nighttime cost variations and common items that contribute to the perception that nighttime construction is more costly. A study by IDOT found that 76 percent of the STAs have the perception that nighttime work is more expensive, with administrative expense being a major contributor to the increase (Al-Kaisy and Nassar 2002). Different researchers have, however, concluded that factors other than administration contributed to the increase in nighttime construction cost.

Construction Costs

Following are the costs directly related to performing the work items of a contract and how they are influenced.

Labor Cost

Nighttime operations may require overtime or a labor premium shift differential. Either one increases hourly labor costs and can also increase agency costs, but such increases are often offset by better productivity. Better productivity derived from more efficient operations leads to reduced contract costs. Union agreements are a labor cost factor that must be carefully considered and addressed when an agency proposes a nighttime work schedule.

A second component of possible labor cost increases is the actual time available during a shift to perform work. If it is necessary to establish and remove traffic control for a night shift, this affects labor cost. The workforce may have to be paid a standard eight-hour shift but cannot begin work until the traffic control is in place and must quit productive work early so the traffic control can be removed and the travelway reopened. In such situations, the worker is paid for a full eight-hour shift but works a shorter time period (Rebholz et al. 2004).

Equipment Cost

Because of the lost production that would result if a critical machine experienced a breakdown during a night shift, contractors often place standby machines on nighttime projects. Machine downtime can also have a more significant loss-of-productivity impact at night due to the unavailability of parts or a replacement rental (Rebholz et al. 2004). An additional cost may be the expense of attaching special light apparatuses to operating equipment.

Material Acquisition

Procurement of materials and supplies is not always possible after the normal business day. Such conditions may force the contractor to have several shifts for transporting materials or create a necessity for storage areas. If not owned by the contractor, concrete and asphalt plants may charge extra for operating at night. Hancher and Taylor (2001) found, however, that because of less congestion, easier delivery of materials to the project resulted in decreased costs. Nighttime concrete and asphalt work can be a problem in cold climates, while in warm climates it can be an advantage.

Tip

The material cost issue is driven more by the quantity requirements. Night work for asphalt or concrete can be very expensive when small quantities are involved (CFLHD (Central Federal Lands Highway Division) 2008).

Traffic Control

Nighttime traffic control often requires additional elements beyond those necessary when work is conducted only during the day. A study for the Virginia Department of Transportation (VDOT) recommended specifically: (1) improving the visibility of traffic control devices, (2) improving the visibility of workers, (3) improving the visibility of work vehicles, (4) decreasing traffic speed and increasing driver attention, (5) decreasing glare from work lighting, and (6) instituting measures to manage traffic queuing (Cottrell 1999).

Tip

Consider nighttime full- or partial-closures as alternatives to resetting traffic control.

If night work requires extensive mobilization of traffic control devices, construction equipment, workers, and demobilization at the end of the shift on a nightly basis, the project will have significantly higher traffic control costs. While this situation adds to traffic control costs, the time required to install and remove the traffic control also limits the shift's productive work time (Bryden and Mace 2002b).

Portable concrete barriers, which would not be needed for daytime work, may be necessary for nighttime traffic control to protect workers when traffic volumes and speeds are relatively high. The NYSDOT recommended early on, if feasible, a total shutdown and reasonable detour or, without a reasonable detour, that work be done behind barriers in traffic (NYSDOT 1991). Good planning during project development is an effective way to limit and manage traffic control costs.

Lighting Expense

The provision of nighttime lighting is a cost not experienced with daytime work. Lighting is a critical necessity for a safe work zone and productivity, and it can have an impact on the quality of the work.

Schedule Cost Effect

The project duration affects total construction costs. Working at night may allow a project to be completed sooner than if it had been accomplished during mid-day off-peak work hours over more days. Alternatively, a night schedule with a partial closure might be chosen over a total closure during the day and this could increase the project's duration (Hinze and Carlisle 1990b).

Indirect Cost

The agency's project staffing cost must be carefully considered. It may be necessary for the STA to pay inspectors and quality control laboratory personnel a premium shift differential. Nighttime operations may, moreover, require the use of law enforcement and other personnel at times or in additional numbers.

Training about nighttime safety issues and safety practices may be needed for workers who have not had such training or who have not had such training immediately prior to the project. Planners, designers, and field staff of both the highway agency and the contractor involved are appropriate participants in training for nighttime work-zone safety (Bryden and Mace 2002a, 2002b).

Key Take-Away

Agency decision makers need to be available at night and it may be necessary to have project consultants on call as well. The ability to get answers is one of the contracting community's major concerns when bidding and planning nighttime work. It is best that on-site project meetings also be held at night so everyone has a clear understanding of the work environment.

Other Costs

Besides construction costs, other types of costs relevant to nighttime construction are road user costs, business costs, and possibly costs resulting from accidents in the work zone. Most transportation agency personnel believe nighttime construction results in reduced road user costs. Given that traffic volume is less at night, delay costs go down and therefore decrease vehicle operating cost.

Moreover, by conducting work at night, many businesses are closed and do not suffer inconvenience compared to when construction activity is conducted during the day. However, this effect is dependent on business type.

Most studies show nighttime accidents are less frequent. This is primarily because of less traffic at night. However, nighttime vehicle collisions can be more severe because of alcohol, illegal and legal drugs, and fatigue.

According to national fatal collision data for 2001, 50 percent of all fatal highway accidents occur between 6 p.m. and 6 a.m. Forty percent of the fatal nighttime collisions occur between 6 p.m. and 6 a.m. on Fridays and Saturdays, and if Sunday is included the percent increases to 56. This makes an argument for scheduling nighttime work on a four-day pattern of Monday through Thursday nights.

Key Take-Away

The key to economical nighttime construction is competition. Structure the bid package so it entices contractors to bid. Through conversations with subcontractors and suppliers, contractors have a good feel for the bidding environment and, with competition, they may not put extra markup on a nighttime project.

Considerations in Estimating Nighttime Costs

The effect on productivity and, therefore, project cost is a function of the type of work and continuous work hours allowed. In addition to the work hours issue, decreased visibility and greater difficulty communicating with supervisors and/or technical support staff are two other factors that can have a negative effect on productivity and increase cost.

Another factor that may have a negative effect on productivity is the longer setup/take-down times for traffic controls and lighting. A project development process that considers work-zone lighting carefully and minimizes the necessity to re-establish traffic control repeatedly will decrease the cost of nighttime work.

Some items of work can be performed faster at night, while others, such as painting, are difficult because of shadows. Before writing the project special provisions, STA staff should go through each work activity of the project to identify which items should not be a problem to accomplish at night (such as paving and hauling dirt) and which will be difficult to perform at night (such as erecting steel girders).

After completing this step on a few projects, agency staff will become aware of the work items that can typically increase project cost and possibly find ways to allow such work during daytime hours.

Erecting steel girders at night can be very tricky because it is difficult for crane operators to judge distance against the dark sky. On the other hand, bolting up steel can be accomplished efficiently at night because it is a close-range activity. On a project in Washington State, a 10-ft deep girder bridge over the Interstate was bolted up in a single night shift.

Key Take-Away

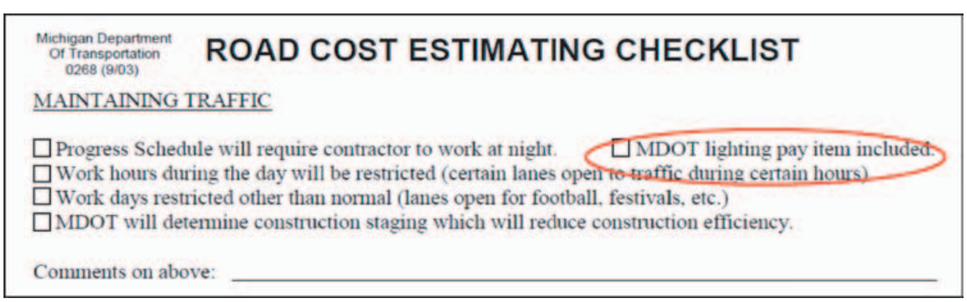
To control project costs, STAs need to dedicate much more effort to planning.

The record of the items affecting nighttime construction cost should be included in a checklist and the list should be available to those responsible for estimating project cost. MDOT has estimate-preparation questions specifically for nighttime work, with one of them being the lighting costs (see Figure 7.1). In addition to the checklist, MDOT includes nighttime cost items within its project-scoping sheet, together with other temporary traffic maintenance items.

Agencies can have different means and methods for estimating nighttime project costs and the items that are included in the estimate. Consequently, specific work items required for working at night may be included in a lump sum cost item.

When lighting and traffic control for a nighttime project are bid as lump sum nighttime costs, it is very difficult to produce accurate future cost estimates from that lump sum, given that the historical cost breakdown is not available to the estimator. Furthermore, when nighttime items are lumped, it is impossible to quantify nighttime/daytime cost differences later.

Consequently, this research team recommends that lighting be specified and paid by types of lighting equipment: mobile light towers; balloon lights; semi-permanent high-mast lighting systems; and light towers on paving, milling, and finishing machines. Data from such pay items will provide cost information for estimating future projects and will make it easier to control the costs during the construction phase of the project.


Michigan Department Of Transportation 0268 (9/03)

ROAD COST ESTIMATING CHECKLIST

MAINTAINING TRAFFIC

☐ Progress Schedule will require contractor to work at night. ☐ MDOT lighting pay item included.
☐ Work hours during the day will be restricted (certain lanes open to traffic during certain hours)
☐ Work days restricted other than normal (lanes open for football, festivals, etc.)
☐ MDOT will determine construction staging which will reduce construction efficiency.

Comments on above: ____________

Figure 7.1. MDOT road cost estimating checklist.

Analysis of Cost Variations for Daytime versus Nighttime Work

It is often difficult to determine the true cost difference between daytime and nighttime construction projects because of the bidding and costing processes involved. Most agencies bid projects on a unit-cost basis. Such bid prices include the cost of labor, equipment, and materials for each work item.

At the time of the bid, the project specifications indicate when (day or night) the project work will be performed. Agency officials are also aware that different contractors use different cost methodologies and different pricing strategies in preparing project bids. Consequently, officials say that they cannot readily determine the cost differential for nighttime construction or the cost of comparable work performed as a nighttime, as opposed to a daytime, construction project.

Several studies on cost differentials indicate that lighting has the highest impact on the cost differential. Work quality and safety both require good lighting and visibility. Other project tasks/items, such as traffic control, inspection, and labor pay premiums, do not show significant differences in cost when performed at night.

Material costs may be increased or decreased depending on two factors: whether or not contractors have their own plants and the magnitude of quantities (not total quantity) required per operation. For example, a nighttime project that requires the contractor to place minor quantities of concrete or asphalt on a repeating basis will likely incur major cost differences when compared to such a situation happening during a normal work day when it is easier to schedule deliveries.

Individual work item cost can be significantly different when comparing cost for daytime and nighttime work. However, higher or lower work item cost differentials are not consistent across projects. These differences may be more a case of project location (i.e., remote areas versus urban locations) and of the experience and/or abilities of the contracting pool with nighttime work.

The number of nighttime project offers to contractors also affects prices. A continuing series of nighttime projects should decrease bid prices as contractors gain experience, a reliable workforce, and also purchase the special equipment necessary for nighttime work, such as light plants or special lights for machines.

The magnitude of the cost differences between daytime and nighttime work items depends on a variety of factors besides the issue of daytime versus nighttime. Traffic volume and the nature and complexity of work, as well as schedules, were found in some studies to have more of an impact on cost than the time of day when the work was performed. The conclusion is that, while nighttime scheduling can affect cost, many other factors are often the primary cost drivers.

Key Take-Aways

When estimating nighttime construction work, it is necessary to consider all conditions affecting the work carefully. In respect to nighttime work, the effect of repeatedly needing small quantities can be much more significant in increasing cost than in the case of daytime work. At the same time, ease of delivery can improve production and reduce cost. Lighting, shift-differential pay, and, possibly, safety equipment may increase item and total project cost, but this effect can be mitigated by better productivity.

Faulty Analysis

The New York State Comptroller (1999) compared daytime and nighttime costs of 20 project components from six nighttime construction projects. The *average* price for each item from *all* bidders was computed, rather than the price from only the low bidders for each component. As expected, including the high bids tended to increase the cost of each component for nighttime construction.

The study found that costs for nighttime construction ranged from a negligible amount to as much as 20 percent higher than the costs for similar daytime operations. In this study, the comparison was based on the arithmetic average cost for each component to a weighted average cost of these same components. Therefore, a follow-up audit by the state comptroller compared weighted averages for each component with the weighted average for all projects.

The audit analysis found that costs associated with nighttime construction were generally not as high as indicated in the original study. As an example, the cost of asphalt was found to increase by only three percent versus 16 percent from the previous report (New York State Comptroller 1999).

As the New York State Comptroller found, the analysis used in many studies of nighttime construction costs exhibits weakness in its methodology. Therefore, STAs should implement systems based on sound methodologies to accumulate pertinent cost data for estimating future nighttime projects.

Best Practices on Minimizing Cost

Many options are available to minimize the increase in total project cost or even item cost for working at night. The key is to institute careful planning early in project development. For example, a lane-closure option should be considered against a total road closure. Different traffic control costs and very different productivity effects are involved in planning decisions. Closure options affect productivity and project duration, which, in turn, affect total project costs.

Options must be evaluated based on total cost to accomplish the work and convenience to the public. Once the need to perform work at night is identified, agencies should carefully review the material quantities required and whether or not a continuing sequence of nighttime jobs is feasible.

As discussed in Chapter 5, Productivity, the CA4PRS tool is very good for modeling construction operations to evaluate productivity and cost. CA4PRS can be used to investigate different lane-closure schemes and different rehabilitation strategies. The experience of WSDOT in reconstructing two lane-miles of portland cement concrete (PCC) pavement on I-5 in 2005 through downtown Seattle provides excellent insights into the use of this tool.

Resource

A review of the WSDOT I-5 project and use of CA4PRS can be found at: http://pavementinteractive.org/index.php?title=WSDOT:CA4PRS_Case_Study_1-_I-5_Olive_To_James/Project_Background.

Traffic control and lighting can be major contributors to any increased cost for night work. Therefore, a continuing sequence of jobs allows contractors to spread the ownership cost of the required lighting equipment over more work hours and should reduce project cost.

In addition, the contractor's nighttime workforce does not need to be retrained repeatedly. With a single project, the agency is continually paying for each contractor's learning curve to attain efficient nighttime operations.

Experience with nighttime operations by both STAs and contractors has proven in many locations that early estimates of increased cost can be reduced significantly, especially by developing traffic control plans that maximize productive work time.

An important cost driver may be weather conditions, which can limit paving operations. Cooler nighttime temperatures can be better for concrete paving, but low temperatures may limit asphalt paving operations.

Clearly, nighttime construction does not need to cost more when applied to the appropriate setting with good planning.

Tip

Frequently, both the traffic control and the construction operations at night are very complex, and the two operations must be staged in the proper sequence to maximize efficiency and safety. Therefore, traffic control plans should be subjected to a careful review to ensure that all essential elements are included and that non-applicable elements are excluded.

Tip

When considering nighttime work, be sure to allow closures that provide a minimum of eight hours of actual work time. It takes almost as long to setup and tear-down for five hours as it does for eight, so an eight-hour shift yields a better setup/tear-down to actual work ratio.

Tip

If traffic volumes are lower than predicted at either end of the work shift, it may be acceptable to lengthen the work shift with little or no additional impact on traffic. Lengthening the shift generally improves productivity and reduces costs.

Tip

Consider contract specifications that require permanent project lighting be installed early in the work schedule.

Conclusions

The important nighttime cost impact factors are lighting expense, additional or different traffic control measures, and labor premiums for overtime or shift differentials. Other causes of possible increased costs are premiums necessary to make suppliers available, indirect costs such as training in nighttime safety practices, standby equipment, and schedule cost effects.

However, some of these costs can be decreased significantly or offset by implementing a continuing sequence of nighttime jobs or through good project planning early in project development.

The literature provides cases of disagreement as to whether nighttime construction costs are actually greater than those experienced with daytime work. The New York State Comptroller's audit of cost experiences in that state pointed out that most cost comparisons have used flawed methodologies. Therefore, it appears that, in most cases where higher costs were reported, multiple factors affected cost besides the nighttime work issue and the other factors were significant contributors to the reported cost increases.

Key Take-Away

When project planning and coordination are taken to a higher level, it is possible to control nighttime construction costs and deliver quality work.

Tip

Contractors equate risk to dollars. Therefore, to decrease the risk to contractors bidding on nighttime work and, consequently, decrease cost, agencies must be willing to have decision makers available during all work hours; doing so may result in higher agency overhead cost, but much lower bid prices.

Resources

- **MDOT—Road Cost Estimating Checklist** http://www.michigan.gov/documents/MDOT_0268_Road_Cost_Est_120543_7.pdf.
- **MDOT—Project-Scoping Sheet** http://www.michigan.gov/documents/MDOT_Project_Scoping_120537_7.pdf.

CHAPTER 8

Safety

Most STAs have adapted work-zone safety standards based on the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) (FHWA 2009) and other FHWA guidance. These standards and guidelines provide a current state of practices and procedures to promote safety and mobility during construction and maintenance operations. The guidelines should be considered carefully and applied under the special conditions of nighttime work.

Resource

Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD)
http://mutcd.fhwa.dot.gov/
http://mutcd.fhwa.dot.gov/pdfs/2009/mutcd2009edition.pdf

NCHRP has undertaken studies and published reports specifically addressing nighttime construction activity. Two very important NCHRP reports on nighttime construction that address safety and work zones were produced by James E. Bryden and Douglas J. Mace in 2002; these are *NCHRP Report 475: A Procedure for Assessing and Planning Nighttime Highway Construction and Maintenance* (2002a), and *NCHRP Report 476: Guidelines for Design and Operation of Nighttime Traffic Control for Highway Maintenance and Construction* (2002b).

Introduction

Nighttime project work activities present a distinct set of hazards to both construction workers and the traveling public. Because of the reduced visibility commonly associated with nighttime work zones and possible driver impairment at night, the safety of construction personnel and the traveling public must be addressed in a very proactive manner.

The significant hazards imposed by nighttime construction activities are attributed to the following (Arditi et al. 2004):

- Decreased visibility.
- Glare from work-zone lighting and vehicles passing through the work zone.
- Higher vehicle speeds.
- Driver impairment by alcohol, drugs, or fatigue.
- Driver confusion.
- Vision reduction of older drivers.

These factors lead to higher nighttime work-zone fatalities compared to daytime work-zone rates (Arditi et al. 2004). Numerous studies have been conducted to determine accident causes and ways to prevent both worker accidents and traveling public accidents within the work zone.

While 53 worker fatalities in twilight or nighttime highway work zones were caused by traffic for the period 1992 to 2000, 17 worker fatalities were caused exclusively by the construction work for the same period (Bureau of Labor Statistics).

Roughly 76 percent of the twilight/nighttime highway work-zone fatalities were traffic-related with 53 percent due to vehicles entering the work area, 13 percent due to impaired drivers, and 10 percent due to workers stepping into traffic. Therefore, traffic through nighttime work zones clearly poses a significant hazard to the workforce.

Key Take-Away

Planning for safe night construction needs to address both construction operations and traffic through the work zone.

Important work-zone enhancements that improve nighttime construction safety are as follows (Bryden 2004):

- Good temporary lighting.
- Brighter signs.
- Larger signs.
- More signs.
- Positive guidance.
- More safety devices.
- Driver information—such as clear driver guidance.
- Law enforcement support.
- Worker visibility and training.

Resource

Behavior Study of Merge Practices for Drivers at Work Zone Closures
http://www.intrans.iastate.edu/research/detail.cfm?projectID=147399822

Safety Precautions

Many safety actions during construction are the same for daytime and nighttime construction activities. Table 8.1 indicates the factors needed to prevent the root causes of construction accidents (Toole 2002). These root causes and preventive actions are applicable to both daytime and nighttime construction. However, for nighttime construction, the emphasis on safety needs to be increased.

Lighting to Enhance Safety

During nighttime construction, proper and adequate lighting is required both to ensure construction quality and to reduce the likelihood of accidents. Adequate lighting helps workers perform work tasks in a productive and safe manner. Lighting must also be established so it does not create glare for motorists entering the work zone and, therefore, create an unsafe condition for the traveling public.

High-mast lighting, instead of portable lights, is recommended during all phases of nighttime project work. The most common non-glare lighting equipment for nighttime construction is the balloon light. To achieve a safe work zone, lighting plans should be developed and carefully reviewed to minimize glare.

Table 8.1. Factors needed to prevent root causes of construction accidents (Toole 2002).

Root Cause of Accident	Preventive Actions
Lack of proper training	• Provide task-specific safety training • Test knowledge or observe employee • Provide access to training records
Deficient enforcement of safety	• Monitor work on frequent basis • Know safety requirements for task • Enforce safety
Safety equipment not provided	• Provide proper safety equipment for the task • Enforce use of equipment • Inspect and maintain safety equipment
Unsafe methods/sequencing of construction tasks	• Establish proper methods • Establish proper task sequencing • Control methods and sequencing
Unsafe site conditions	• Establish a clean and uncluttered work-site culture • Observe site conditions regularly • Control site conditions
Failure to use proper safety equipment	• Observe employees performing task constantly • Influence behavior through: – Evaluations – Training – Incentives
Poor attitude toward safety	• Observe and interact with workers frequently • Influence attitude through: – Evaluations – Training – Incentives
Sudden deviation from prescribed behavior	• Evaluate employees' emotional condition daily • Evaluate physical condition daily

Nighttime construction lighting should follow standard or special provisions imposed by local governments or by the Occupational Safety and Health Administration (OSHA). Generally, different types of construction activity require certain levels of illumination to ensure adequate lighting for the tasks.

The three categories of nighttime construction illumination levels are detailed in Table 8.2 (Ellis et al. 2003). Keep in mind when reviewing Table 8.2, fixed roadway lighting typically emits less than 20 lux.

Table 8.2. Summary of illumination guidelines by activity (Ellis et al. 2003).

Category	Illumination (lx)	Heights of Candles	Recommended For	Sample Activities
I	54 lx	5 ft	General illumination of activity areas; mainly for visibility in the area where crews are working	• Excavation • Embankment • Landscaping
II	108 lx	10 ft	Illumination on and around the construction equipment; use for seeing tasks	• Resurfacing • Paving • Bridge decks
III	216 lx	20 ft	Tasks that present high visual difficulty requiring close attention by workers	• Mechanical • Electrical • Detail work

Note: lx is the symbol for lux, the SI unit of illuminance.

Higher illumination levels are recommended for activities that require higher levels of discernibility, such as electrical work. A lower illumination level is recommended for activities like excavation. Further information on nighttime illumination guidelines is available in Chapter 3, Illumination.

Nighttime Visibility and Retroreflectivity

An important aspect of nighttime construction safety is worker visibility and retroreflectivity of signing. The requirement to be visible is vital for the safety of the workers. Retroreflectivity, or retroreflection, can be defined as a ratio of the amount of light returned from a traffic sign versus the amount hitting the traffic sign. It is a way of measuring the efficiency of the material used to surface traffic signs.

According to the American National Standards Institute/International Safety Equipment Association (2006), accidents are prevented when the workers in the work-zone area are visible and can be easily detected by equipment operators and motorists. Therefore, it is essential for transportation agency personnel and construction workers to use safety equipment and that traffic signs and devices be highly visible and retroreflective.

Tip

Be sure that all protective clothing (i.e., vest) complies with latest ANSI II-III requirements.

Retroreflectivity of Traffic Signs

Maintaining retroreflectivity of traffic signs is crucial to providing safe guidance to nighttime traffic through the work zone. The MUTCD specifies different methods of inspection that are necessary: visual inspection method by using the comparison panel procedure, calibrated sign procedure, and consistent parameter procedure and a retroreflectivity measurement method, through measurements made with hand-held devices. Traffic control devices, including traffic barrels and cones, must also have clean reflective strips to guide motorists.

The MUTCD has guidance concerning maintaining traffic signs at a minimum level of reflectivity. It also includes guidance concerning setup and maintenance of signs. Figure 8.1 provides some of the language in the MUTCD on minimum retroreflectivity.

Tips

- The objective is to ensure that signs and channelizing devices are in good condition, visible, and retroreflective for the traveling public.
- Signs and all devices must be kept clean.

Tips

- Change vehicle and equipment paint to attention-grabbing colors.
- Add retroreflective tape to construction vehicles and equipment.

High-Visibility Personal Protective Equipment

OSHA standard 29 CFR 1926.28(a), Safety and Health Regulations for Construction, explicitly states the employer is responsible for requiring that workers wear the appropriate personal protective equipment (PPE) in all operations where an exposure to hazardous conditions exists or where the standard indicates the need for using such equipment.

Section 2A.08 Maintaining Minimum Retroreflectivity

Support:

01 Retroreflectivity is one of several factors associated with maintaining nighttime sign visibility. (see Section 2A.22).

Section 2A.22 Maintenance

Guidance:

01 Maintenance activities should consider proper position; cleanliness, legibility, and daytime and nighttime visibility (see Section 2A.09). Damaged or deteriorated signs, gates, or object markers should be replaced.

02 To assure adequate maintenance, a schedule for inspecting (both day and night), cleaning, and replacing signs, gates, and object markers should be established. Employees of highway, law enforcement, and other public agencies whose duties require that they travel on the roadways should be encouraged to report any damaged, deteriorated, or obscured signs, gates, or object markers at the first opportunity.

03 Steps should be taken to see that weeds, trees, shrubbery, and construction, maintenance, and utility materials and equipment do not obscure the face of any sign or object marker.

04 A regular schedule of replacement of lighting elements for illuminated signs should be maintained.

Figure 8.1. MUTCD language on minimum reflectivity (FHWA 2009).

Key Take-Away

Proper clothing is considered the most important element to ensure worker safety.

High-visibility PPE protects workers from potential construction hazards and helps in recognizing workers in decreased light situations. All personnel—whether contractor or agency—in a nighttime work zone must wear highly visible outer garments. High-visibility safety garments must be worn at all times.

The MUTCD outlines the standards for high-visibility clothing explicitly. The garments must be retroreflective and visible from a minimum distance of 300 m or 1,000 ft. The categories of available high-visibility PPE and examples are listed in Table 8.3.

Safety garments are normally made in accordance with several industry standards worldwide:

- British Standard Protective Clothing—High-Visibility Clothing BS EN 471:1994.
- European Standard Retroreflective Materials and Devices for Road Traffic Control Purposes AS/NZS 1906.4 (1997).
- Canadian Standard of High-Visibility Safety Apparel CAN/CSA Z96-02.

Resources

ANSI/ISEA 107-2004 MADE EASY: A Quick Reference to High-Visibility Safety Apparel. 3M. Occupational Health and Environmental Safety Division. 2005. http://mws9.3m.com/mws/mediawebserver.dyn?6666660Zjcf6lVs6EVs666NA8COrrrrQ-.

Table 8.3. High-visibility personal protection equipment types and examples (Abraham et al. 2007).

Type	Examples
Safety vests	Regular safety vests and self-illuminating safety vests
Safety shirts	Long sleeves, short sleeves, winter shirts, and T-shirts
Safety pants	Long pants (trousers) and short pants
Headgear	Hard hats, caps, winter hats, hard hats, high-visibility cover
Outerwear	Coats, rain suits, windbreakers, coveralls/ jumpsuits
Accessories	Retroreflective strips, ankle and hand bands, high-visibility gloves, sash belts, batons, and flashers

Table 8.4. High-visibility safety garments by performance class (Abraham et al. 2007, originally from ANSI/ISEA 2004).

Performance Class	Description
1	Provides the minimum amount of required material to differentiate the wearer from the work environment
2	Superior visibility for wearers by the additional covers of the torso and is more conspicuous than Class 1
3	Greater visibility to the wearer on both complex backgrounds and through a full range of body movements by placing retroreflective material on the arm and/or leg
4	Waistband trousers and shorts that meet all the requirements for the retroreflective and background material in performance Classes 1, 2, and 3

ANSI/ISEA 207-2006: American National Standard for High-Visibility Public Safety Vests. 3M. Occupational Health and Environmental Safety Division. 2008. http://multimedia.3m.com/mws/mediawebserver?mwsId=SSSSSu7zK1fslxtUnxmUmY_eev7qe17zHvTSevTSeSSSSSS—&fn=What%20is%20ANSI%20207%20Standard.pdf.

In the U.S., the use and design of high-visibility safety garments falls under the responsibility of the International Safety Equipment Association (ISEA) in collaboration with the American National Standards Institute (ANSI). The ANSI/ISEA published standards establish different performance criteria for the design and use of safety apparel.

According to ANSI, high-visibility safety garments are PPE intended to provide conspicuity during both daytime and nighttime use. Conspicuity may be increased if high contrast is provided between the garment and the environment against which it is seen. High-visibility safety garments are categorized into four different performance classes, as shown in Table 8.4.

These four performance classes are further recommended for different types of working conditions, as shown in Table 8.5. Different work-zone conditions—traffic speed, volume of activity, minimum area of background/retroreflective material—set the performance class.

The MUTCD specifically requires all workers within the right-of-way or work zone to wear high-visibility apparel. The workers include traffic personnel and uniformed law enforcement officers. Figure 8.2 provides the language of the safety apparel portion of the MUTCD.

Considerations

The MUTCD includes a specific high-visibility apparel recommendation for flaggers. Nighttime flaggers should wear high-visibility safety apparel that meets the Performance Class 3 requirements of ANSI/ISEA 107–2004 (FHWA 2009).

The apparel background (outer) material color shall be fluorescent orange-red, fluorescent yellow-green, or a combination of the two as defined in the ANSI standard. The retroreflective material shall be orange, yellow, white, silver, yellow-green, or a fluorescent version of these colors, and shall be visible at a minimum distance of 1,000 ft. The retroreflective safety apparel shall be designed to clearly identify the wearer as a person.

Table 8.5. Working conditions for which a performance class is applicable (Sant 2001).

	Performance Class		
Conditions	1	2	3
Speed of traffic	25 mph	25–50 mph	Above 50 mph
Volume of activity	Low	Medium	High
Minimum area of background/ retroreflective material	217 sq in./ 155 sq in.	775 sq in./ 201 sq in.	1,240 sq in./ 310 sq in.

Standard:

04 All workers, including emergency responders, within the right-of-way who are exposed either to traffic (vehicles using the highway for purposes of travel) or to work vehicles and construction equipment within the Temporary Traffic Control (TTC) zone shall wear high-visibility safety apparel that meets the Performance Class 2 or 3 requirements of the ANSI/ISEA 107–2004 publication entitled "American National Standard for High-Visibility Safety Apparel and Headwear" (see Section 1A.11), or equivalent revisions, and labeled as meeting the ANSI 107-2004 standard performance for Class 2 or 3 risk exposure, except as provided in Paragraph 5. A person designated by the employer to be responsible for worker safety shall make the selection of the appropriate class of garment.

Option:

05 Emergency and incident responders and law enforcement personnel within the TTC zone may wear high-visibility safety apparel that meets the performance requirements of the ANSI/ISEA 207-2006 publication entitled "American National Standard for High-Visibility Public Safety Vests" (see Section 1A.11), or equivalent revisions, and labeled as ANSI 207-2006, in lieu of ANSI/ISEA 107-2004 apparel.

Standard:

06 When uniformed law enforcement personnel are used to direct traffic, to investigate crashes, or to handle lane closures, obstructed roadways, and disasters, high-visibility safety apparel as described in this Section shall be worn by the law enforcement personnel.

Figure 8.2. Language on safety apparel requirement in MUTCD Section 6D.03, Worker Safety (FHWA 2009).

Several research studies have shown that yellow is the most recognizable color during daytime, but orange is better at dusk and during the nighttime.

Tip

Blaze orange was found to be the most conspicuous of the retroreflective trim colors (Abraham et al. 2007).

STA officials interviewed for this guide recommended construction workers wear hardhats, reflective strips, and vests; and full suits and gloves when workers are establishing lane closures.

Two-piece safety apparel tends to provide better visibility of workers when they bend over to perform a construction activity (Cottrell 1997). This apparel is recommended by the industry as a response to the Minnesota DOT (Mn/DOT) request to develop higher-visibility safety apparel. At present, Mn/DOT requires all workers to wear high-visibility vests, caps, and pants to increase worker visibility in construction work zones at all times (Mn/DOT 1997).

The National Institute of Occupational Safety and Health (NIOSH) recommends the use of arm and knee bands to enhance visibility, as well as strobe lights on worker vests for better identification of the workers. However, the performance of safety vests in nighttime conditions is dependent on both the characteristics of the vests (amount of retroreflective material and design of the vest) and the characteristics of the construction/maintenance sites (weather, lighting, and traffic volume) (Arditi et al. 2004).

Safety Management for Nighttime Construction

Construction work zones can create unique safety hazards depending on heavy equipment, materials, and construction activities. The perception is that nighttime construction work exposes the worker and the traveling public to higher risk and severity of work-zone accidents. Many types of hazards are associated with nighttime work, and it is crucial for agencies and contractors to ensure that proper safety measures are exercised.

Construction and maintenance workers should be instructed about the distinctive risks and hazards imposed by nighttime construction. Poor visibility, reduced lighting, worker fatigue, and driver drowsiness and substance abuse are all accident risk factors when a project is constructed at night.

Extra proactive safety measures are, therefore, essential for safe nighttime construction, specifically in the work zone. The safety implications should always be considered, even when the work zone has a very short duration, occupies a very short length, or is located on the shoulder or even beyond the traffic lane.

Transportation agencies and contractors should have proactive safety plans. These safety plans should include the employer's specific policies, guidelines, and practices, which employees are expected to follow to create a safe work environment.

Many agencies within the construction industry, including the Associated General Contractors of America (AGC), the Associated Builders and Contractors (ABC), and the Construction Industry Institute (CII), have produced guideline information for safety management.

More than 170 safety improvement techniques are listed within the CII's *Zero Injury Techniques* (1993) document. This research team recommends that transportation officials and contractors review these techniques and, as appropriate, incorporate them in their safety plans for nighttime work.

Tip

Safety management plans need to be updated and modified regularly based on experiences from past projects, as well as with any project design changes.

Tips

Top five effective ways to manage site safety are as follows (Liska et al. 1993):

- Pre-project planning for safety.
- Safety orientation and training.
- Written safety incentive programs.
- Accident/incident investigations.
- Alcohol and substance abuse program.

Safety Talks

Safety talks are a good way to discuss and disseminate vital information pertaining to nighttime construction safety issues. Talks can be part of meeting agendas or conducted separately.

Safety talks are usually conducted ad-hoc, prior to the start of any work, and they provide a good time to evaluate employee emotional and physical condition.

Safety talks can also be regularly-scheduled, such as daily or weekly. Safety talks during January through April can be used to warn workers about cold-weather seasonal hazards or, in summer months, about possible extreme weather conditions (thunderstorms or heat).

Key Take-Away

Effective communications are the key to addressing nighttime construction safety issues effectively. Safety talks about nighttime construction issues, such as traffic and the causes of crashes, help everyone understand the hazards and what to do in case of an accident.

Key Take-Away

Toolbox talks are short discussions or presentations by supervisors with their crews.

Tip

Daily toolbox safety meetings are used to target hazards of tasks and to emphasize activities that will take place during the work period. Such talks usually focus on a specific topic.

Key Take-Away

Toolbox talks help workers recall their knowledge on safety and, therefore, increase worker safety.

Toward the end of the year, the safety talk sessions may recap the safety encounters experienced throughout the year. The recommendation is to provide adequate information on different topics associated with general safety, together with instructions on specific tasks.

Discussions should include recognition of the need to avoid situations involving the risk, behavior of the road worker toward the traffic, considerations before commencing and during the work, as well as the procedures to follow in case of incidents. A sample safety talk conducted by the NYSDOT includes the importance of being visible at all times by wearing high-visibility apparel, PPE, construction vehicle protection, and maintenance of traffic signs and guiding devices.

Resource

NYSDOT Nighttime Construction Safety Tailgate Safety Talks can be found at: https://www.nysdot.gov/main/business-center/contractors/construction-division/safety-health-information/tailgate-safety-talks.

Tip

Be creative and try to conduct interactive safety talk sessions. Encourage workers to exchange thoughts on safety issues, or conduct a written quiz about the topics discussed. (See the Appendix for a sample safety quiz.)

Safety Inspections

Safety inspections of nighttime traffic control procedures and safety devices should be performed regularly. Safety inspectors may need to be made more aware of the need for good lighting and should inspect lighting constantly.

Tip

Monitoring nighttime traffic can provide data to support planning of future nighttime work.

Contractors should be encouraged to conduct their own safety inspections of vehicles and heavy equipment with attention to lights and backup alarms; work-zone operations; traffic control devices; and signing, markings, signals, traffic systems, and roadway safety appurtenances.

Safety Training and Safety Awareness Programs

Because night workplaces can add demands on workers and can expose them to greater risks than daytime work, additional training is needed to ensure that workers are prepared to meet the added demands. All workers on night projects need to be made aware of the special risks inherent in night work, along with the safeguards and procedures to be followed on the project to compensate for these risks (Bryden and Mace 2002b).

Key Take-Away

Safety training should begin as soon as workers are hired and it is likely the responsibility of the contractor to ensure that workers are given sufficient safety training, but the STA should monitor or even require this training.

Nighttime work-safety training includes, but is not limited to, the following topics:

- Safety rules.
- Worksite policies.
- Safety apparel and general work clothing requirements.
- Being alert for vehicles entering the work zone.
- Procedures for backing vehicles.
- Awareness of backing vehicles.
- Designated parking locations.
- Walkways and crossing points to safely access the worksite.
- Drivers and equipment operators alert for workers on foot at night.
- Specific site hazards (e.g., overhead utilities are very difficult to see at night).

Tip

All workers who complete safety training programs should also be asked to provide written evaluations to determine whether or not they fully understood the training material.

Safety training materials can be produced and distributed to workers in different forms, such as booklets, manuals, digital file storage (CDs and flash drives), charts, and others. Figure 8.3

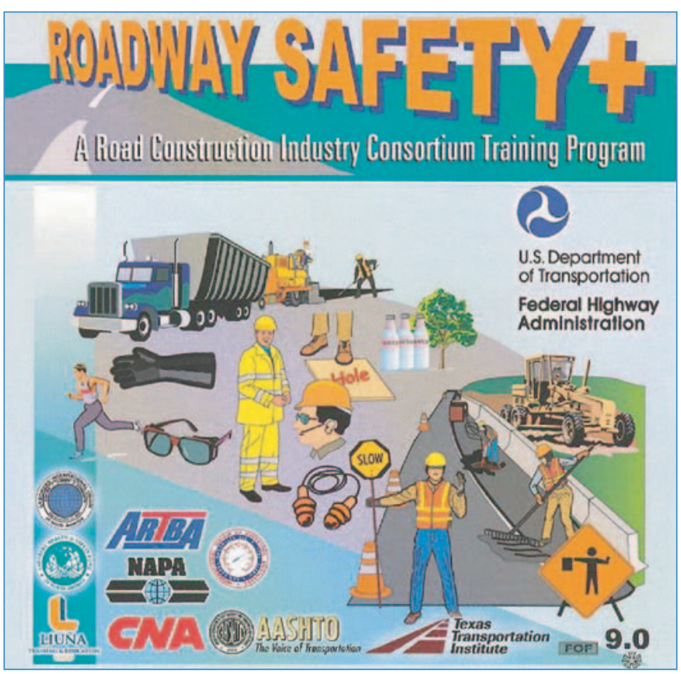


Figure 8.3. Safety training CD by the FHWA.

illustrates an example of a safety training program offered by the National Work Zone Safety Information Clearinghouse.

A webinar session at www.workzonesafety.org/video_viewer.php?id=99c2a7a9-95b9-4642-a80a-e80516d8b652&width=990&height589 takes viewers on a virtual tour of this Roadway Safety+ training program. The program has modules on temporary traffic control (TTC) design and in-depth training on night work. More information can be found at www.workzonesafety.org/node/9748 or by contacting the American Road & Transportation Builders Association in Washington, D.C.

In the case of nighttime work, under the subject of PPE, it is essential to provide workers with the following knowledge on high-visibility apparel:

- When to use the high-visibility apparel.
- Fitting instructions, including how to put on and take off the apparel.
- Importance of using the apparel properly.
- Limitations of use.
- How to store and maintain the apparel.
- How to check for serviceability.
- How to clean or decontaminate the apparel correctly, with complete washing and/or dry cleaning instructions.

Once workers complete the safety training, it is still necessary to repeat critical ideas during toolbox safety talks. Toolbox safety talks provide an opportunity for supervisors and management to observe if workers are wearing the appropriate safety apparel.

Many organizations and agencies conduct safety awareness programs in other languages, such as Spanish to accommodate a Hispanic construction workforce. According to OSHA's training standards policy statement, if an employee does not speak or comprehend English, it is the responsibility of the employer to provide instruction in a language the employee can understand.

Likewise, if the employee's vocabulary is limited, training must be provided to account for that limitation. Employers must inform and train workers in a language they can understand. The importance of providing multilingual safety training cannot be overemphasized.

For safety and in case of emergencies, the FHWA stresses the importance for personnel in the transportation industry to know some basic words in other languages. Therefore, a pamphlet is available to ensure, when it comes to safety issues, everyone may have some basic knowledge of Spanish. Figure 8.4 shows the cover of this two-page pamphlet published by the FHWA. The pamphlet is available at www.workzonesafety.org/files/documents/public_awareness/WZCH-spanishbrochure.pdf.

In addition to safety training, agencies can use other initiatives to promote safety. These include safety awareness programs, awards, and recognitions. As part of the Road Construction Industry Consortium Awareness Program, the Laborers Health & Safety Fund of North America has published a *Roadway Safety+ Awareness Program Night Work Trainee Booklet*. It is a simple but excellent reference (see Figure 8.5).

This booklet covers night work hazards and offers information about specific protections necessary when working at night. It includes tips on how to minimize sleep loss: maintain a strict sleep schedule, make sleep a priority, and, during the night, eat small protein-rich meals and avoid fats and sugars. The booklet is available at http://www.workzonesafety.org/files/documents/training/courses_programs/rsa_program/RoadwaySafety_Booklets_English/RoadwaySafety_Booklet_NightWork_English.pdf.

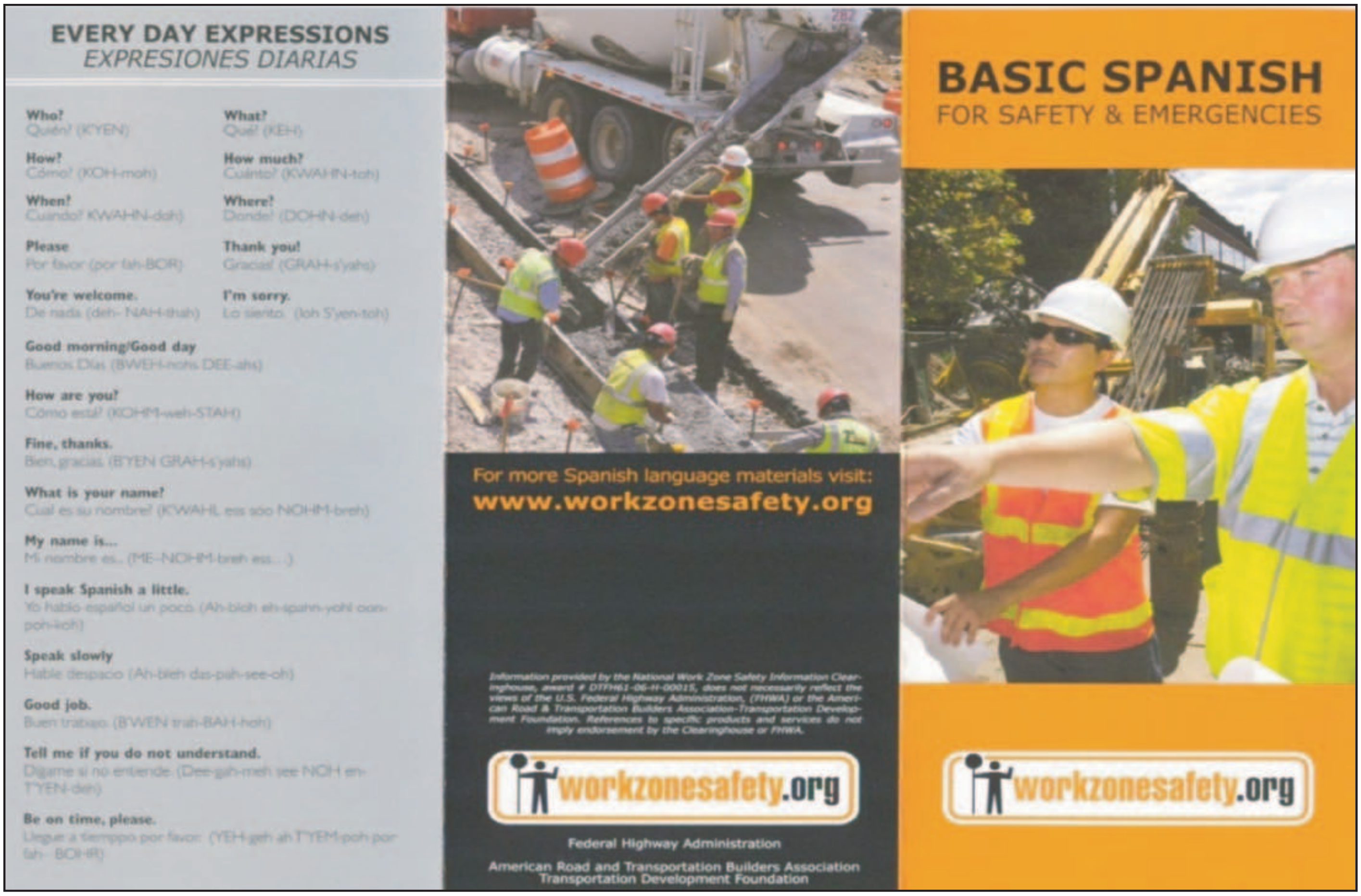


Figure 8.4. FHWA pamphlet of basic Spanish for safety and emergencies.

Tips

Tips for safety training with a bilingual workforce (Business and Legal Resources 2011):

- Establish bilingual companywide safety training.
- Hire supervisors who are bilingual.
- Provide signage (safety guidelines, emergency evacuation, warnings) in the languages spoken by the employees and include diagrams or symbols.
- Pair new employees with bilingual veteran employees who understand and comply with safety and health guidelines.
- Conduct periodic jobsite visits and work with employees in the field.
- Follow up formal training with demonstrations, and have employees demonstrate to one another.
- Conduct safety meetings and toolbox talks to reinforce formal training.

The Iowa DOT has a *Safety Calendar* it uses to spread the safety message. Each page above the monthly calendar contains information on safety issues and safety checklists. This calendar presents basic yet valuable information, acts as a simple communications tool, and serves as a reminder to employees about construction safety. Figure 8.6 provides excerpts from the *Safety Calendar*.

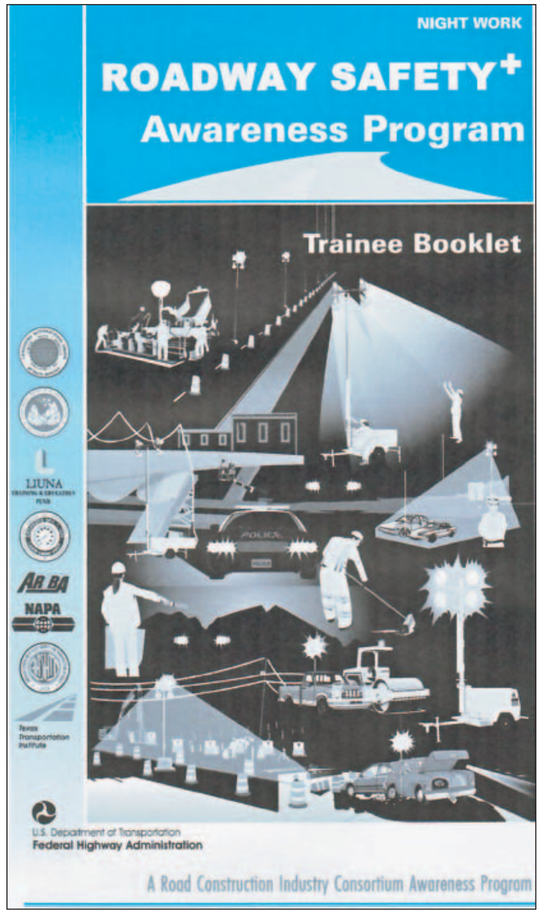


Figure 8.5. FHWA Roadway Safety Awareness Program booklet.

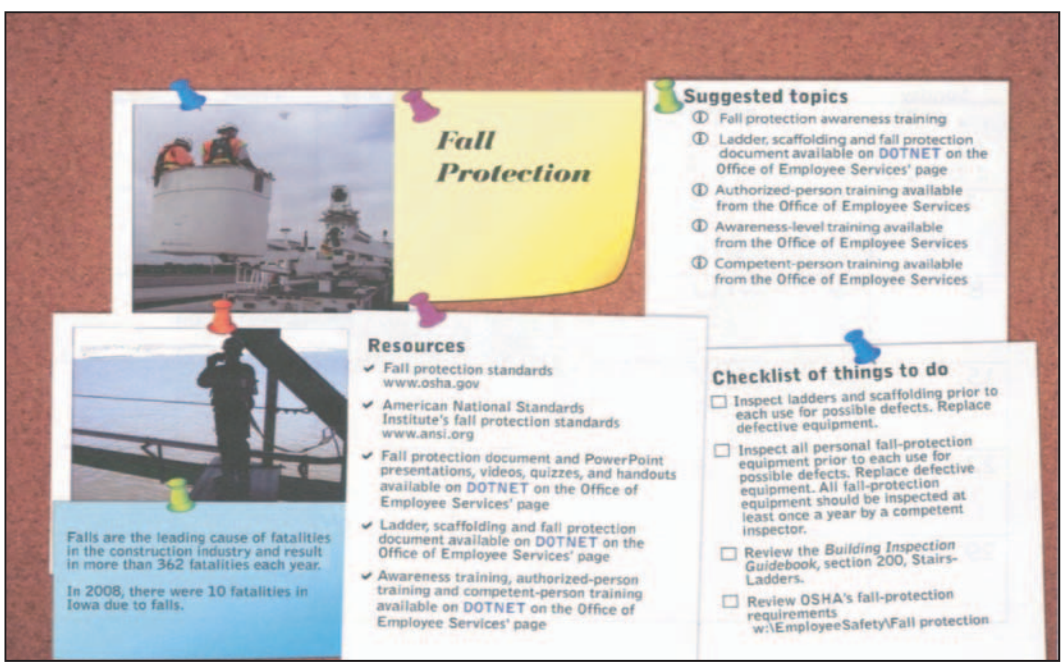


Figure 8.6. Safety Calendar used by the Iowa DOT.

Best Practices for Nighttime Work-Zone Operations

Several methods can be used to provide safe nighttime work zones. Work-zone traffic safety can be improved through good engineering and design practices, enforcement of traffic laws and regulations, and agency procedures.

To ensure that effective work-zone traffic management is implemented, a comprehensive traffic control plan (TCP) that considers the nature of nighttime conditions should be developed for the work-zone area. Development of a proper TCP is extremely important prior to beginning work.

Key Take-Away

The key purpose of a TCP is to offer safe and effective movement of road users within the TCP zones to protect road users, workers, responders to traffic incidents, and equipment. The TCP should consist of information pertaining to the safety of motorists, bicyclists, pedestrians, workers, enforcement/emergency officials, and equipment.

Engineering and Design Practices

Other ideas to improve nighttime work zones include the following:

- Design and installation of TTC devices (Oregon DOT 2009).

Nighttime work zones frequently present higher risk for the traveling public if proper precautions are not exercised. The TTC devices used to deliver information to motorists and to alert them to the presence of nighttime workers and potential roadway threats need to be noticeable and reliable (see Figure 8.7). Visibility of flaggers and their vehicles is required for the security and safety of both workers and the traveling public.

It is essential that devices are set up properly and within the spacing recommended in the MUTCD. In addition, the device should comply with state and local regulations and standards.

- Use of intelligent transportation systems (ITS) for work zones.

The MUTCD recommends the use of ITS for improvement of the work zone in terms of work-zone traffic and control systems (see Figure 8.8). The ITS tools include portable changeable message signs to display delay or speed information ahead of the work zone.

Enforcement of Traffic Laws and Regulations

Tip

The use of law enforcement personnel can help to reduce the speed of motorists entering nighttime work zones.

Agency Procedures

Work Vehicles

For work vehicle protection, warning lights with 360 degree visibility should be required; two lights are better for depth perception and amber is the preferred color. Rotating/flashing incandescent lights are best; strobe lights are not as good. Supplement vehicle warning lights with four-way flashers and retroreflective marking.

Night Flagging

Night flagging is very dangerous. Where flagging must be used, the flagger position must be well lit and the flagger must wear proper retroreflective clothing.

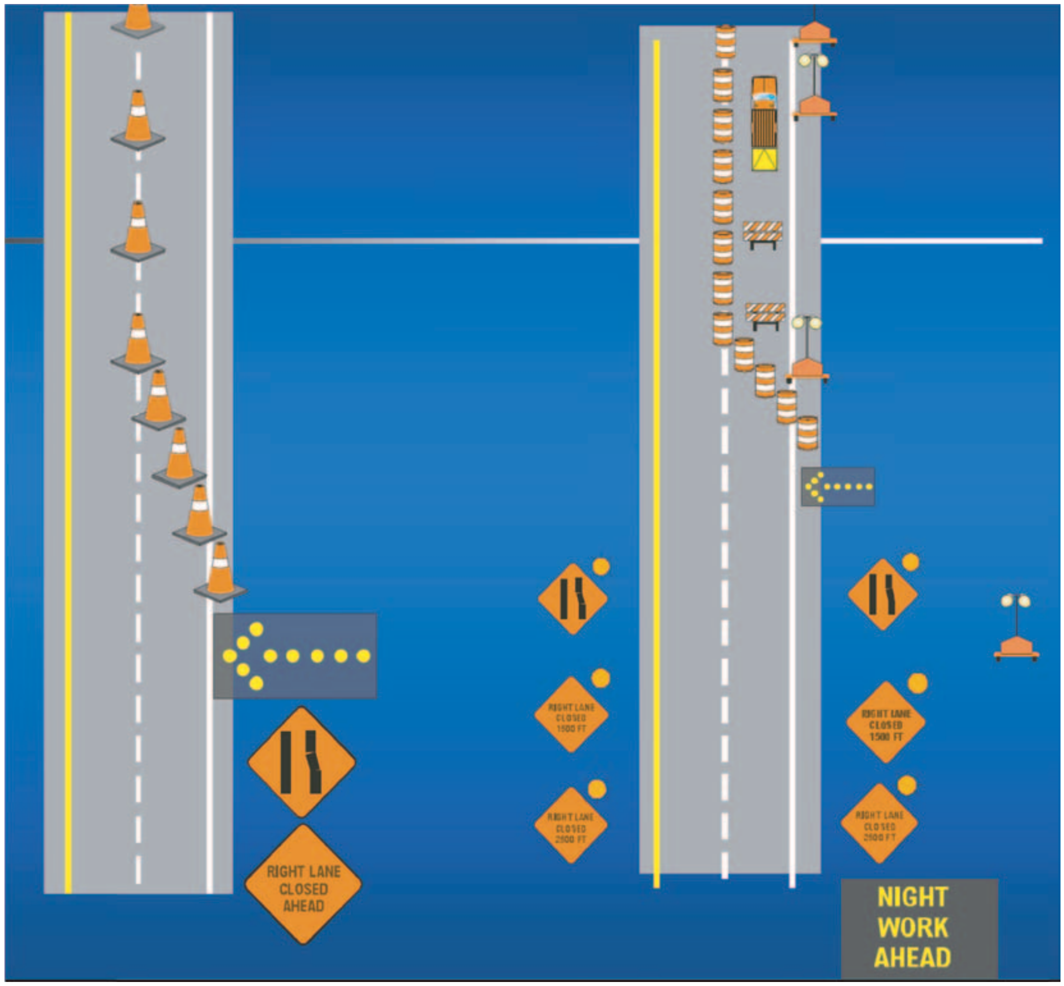


Figure 8.7. Differences in nighttime and daytime temporary lane closures (Bryden 2004).

Full body garments are recommended so that whole body movement is detectable by drivers. A properly-trained flagger, adjacent to a speed limit sign, can reduce average speeds by 5 to 10 mph (Bryden and Mace 2002b).

Tip

Arrange detours and work areas so flaggers are not needed.

Section 6A.01 General

Support:

09 Operational improvements might be realized by using intelligent transportation systems (ITS) in work zones. The use in work zones of ITS technology, such as portable camera systems, highway advisory radio, variable speed limits, ramp metering, traveler information, merge guidance, and queue detection information, is aimed at increasing safety for both workers and road users and helping to ensure a more efficient traffic flow. The use in work zones of ITS technologies has been found to be effective in providing traffic monitoring and management, data collection, and traveler information.

Figure 8.8. MUTCD language on ITS (FHWA 2009).

Tip

Flagging should not normally be considered a speed reduction technique for nighttime construction because flaggers are less visible and the risk to their safety is greater at night (Bryden and Mace 2002b).

Tip

Consider asking contractors for safety plans, especially if nighttime construction will be used.

Tip

Consider requiring safety history for contractor prequalification.

Conclusions

Nighttime construction activities present all the usual construction hazards risks. However, because of decreased visibility, additional safety hazards arise. Therefore, it is extremely important for agencies to take a focused approach to nighttime construction work-zone safety. The issue of visibility must receive constant attention, with contractors required to submit lighting plans and inspectors regularly checking work-site lighting.

Necessary safety measures, such as proper safety plans and safety management, need to be implemented. This includes employer-provided safety training and awareness programs. All workers, including STA personnel, should undergo safety training and possess knowledge on safety precautions when performing nighttime work. In addition, effective and reliable work-zone traffic management should be designed and implemented.

Night work can be safe for workers and work-zone–transiting vehicles. The key to a safe nighttime project is planning, supported by the following:

- Good temporary lighting.
- Effective signs—brighter signs, larger signs, more signs.
- Effective channelization—device spacing, retroreflectivity, warning lights.
- Visible workers.
- Visible work vehicles/equipment.

CHAPTER 9

Communications

A vital part of nighttime construction planning is developing the communication strategy for the project. Agencies must inform the motoring public about activities that will impact traffic, particularly nighttime traffic. The public should be informed of the time, location, duration, and type of work conducted. Efficient communication strategies help the public to understand the reasons for nighttime work, which alleviates many problems associated with nighttime construction (Hancher and Taylor 2001).

Prior to construction, agencies should develop strategies to ensure that relevant information pertaining to the nighttime construction work is disseminated to the public. Communications strategies include communicating with road users, the general public, area residences, and businesses, as well as keeping appropriate public entities fully informed about the construction work zone and the implications for safety and mobility. Proactive communications are part of successfully executing a nighttime construction project.

Resource

The FHWA provides communication strategy guidance in Chapter 2 of its *Work Zone Public Information and Outreach Strategies* guide (FHWA 2005a) at http://ops.fhwa.dot.gov/wz/info_and_outreach/index.htm.

The FHWA recommends that a public information and outreach campaign be developed and executed well before construction begins and monitored continuously throughout the life of the project.

A well-planned and implemented communication campaign mitigates issues by warning drivers of work-zone locations and by supplying both pre-trip and en route information. Such information allows drivers to make knowledgeable choices about routes and when to travel.

This FHWA guidebook can assist transportation agencies in planning and implementing effective communication strategies internally and externally. It focuses on measures taken to convey important information regarding the construction work zone, such as lane and shoulder closings, new traffic patterns, and traffic delay, as well as available travel alternatives, such as different routes and travel modes. Different communications means and strategies are needed to ensure that agencies employ best practices in conveying relevant information regarding nighttime construction.

The Difference Between Daytime and Nighttime Communications

The communication strategies for daytime and nighttime construction may be the same, but the use of specific strategies may depend on different factors. Important aspects to consider when choosing a communications strategy to disseminate nighttime information include the following:

- Project location.
- Size (extent or roads impacted).
- Accessibility.
- Work hours.
- Traffic restrictions.

If the nighttime construction covers a larger area (such as Interstates), possible communication methods include websites, newspaper coverage, newsletters, and fliers or pamphlets. The information included should target a specific audience, such as trucking companies and frequent night travelers.

Fliers or pamphlets should contain information regarding location and nature of the night work activity, including the expected impact on traffic patterns (e.g., x-minute delays can be expected). Any feasible suggestions for alternative travel patterns and routing should be provided. Consequently, the specific work schedule (in hours and days) and the overall duration of the work should also be specified.

If the project involves a night-only schedule, the public must know that daylight travel will be normal. This information can be distributed to trucking companies, and at rest areas and visitor information bureaus. When special events (such as ball games, concerts, and so forth) are near a nighttime construction location, information on detours, closures, and alternate routes should be publicized ahead of time to help mitigate traffic disruption.

Communications Plan

A public information plan is important and should include information such as different types of communication tools and means and methods to disseminate information to construction personnel and stakeholders (internally) as well as to the public (externally). The information provided needs to be credible, accurate, and timely; and it needs to be updated continuously. It is best if the plan is developed in advance and the activities described managed and monitored by communications personnel or a public information officer.

The communications strategy chosen should be able to cater to the majority of the traveling public, particularly regular users of the route. Communications should be started early to allow businesses and emergency service providers to develop appropriate contingency plans.

The FHWA, through its Work Zone Mobility and Safety Program, has outlined several means and methods for communication strategies that are commonly used to disseminate project information to the public.

One common approach is to implement effective branding developed specifically for the project. Project branding can take a variety of formats, which include, but are not limited to logos, distinctive project names, catchphrases, and "trademark" graphics. By branding in several formats, the target audience can recognize any information related or pertaining to the work zone more easily. In addition, the requirement of a brand on all official information assists the public in validating the accuracy of the information being issued.

Several STAs, including the Delaware Department of Transportation (DelDOT) and IDOT, have used an innovative approach to create public awareness for their road projects. The creation of an animated character named the Traffic Creep was part of the DelDOT public information campaign for the I-95 project in 2005 (see Figure 9.1).

IDOT used the same approach by developing Jack Hammer for its I-74 project in Peoria (see Figure 9.2). WSDOT, on its I-90 project, created its Burl the Squirrel mascot to explain the planned improvements to I-90 in a user-friendly manner. These characters were used on a

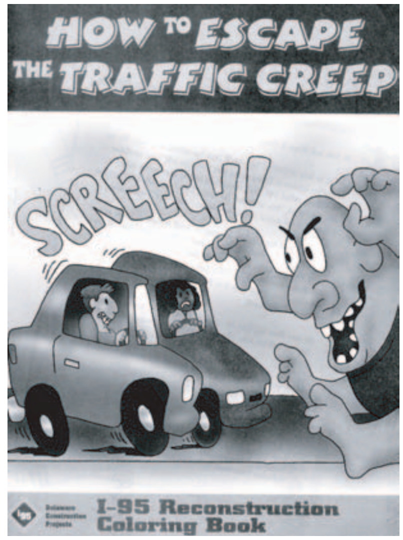


Figure 9.1. "Traffic Creep" character for I-95 project (Delaware DOT).

variety of public awareness materials, including their newsletters, website, and signs, as well as a costumed character at schools and community events.

Types of Information Dissemination to the Public

Whether the work performed at night is operation and maintenance work or regular construction activities, it is imperative for agencies to provide relevant information. Outreach campaigns generally incorporate three messages:

- Safety first.
- Plan ahead to minimize delay and frustration.
- We care.

Safety First

The most important message is to encourage motorists to take safety precautions to protect themselves and highway workers. To prevent accidents, drivers should be reminded continuously to adhere to posted speed limits and to stay alert (for lane changes, slowing traffic, etc.).

Figure 9.2. "Jack Hammer" for I-74 project (Illinois DOT).

Plan Ahead to Minimize Delay and Frustration

The disruptions caused by a work zone can be reduced if travelers plan ahead. In addition, if travelers know what to expect, they will be less frustrated about delays. Some of the information that should be disseminated includes the following:

- Number of lane closures, duration, and length of closure.
- Nighttime construction schedule, which includes description of the activity and the start and end of the activity.
- Traffic maintenance and access information for the affected roads, which includes residents and businesses affected, alternate routes and detours, and a contact for further information.
- Unusual traffic conditions (such as road obstructions) within 15 minutes of the affected areas.

We Care

Motorists are more willing to cope with disruptions and cooperate with directions when they feel all necessary steps are being taken to make things easier.

Tips

- Provide the most accurate, timely, appropriate, and up-to-date information.
- Provide information that will help motorists navigate the construction work zone.

Process and Procedures in Disseminating Information

Once the decision to perform nighttime construction is made, begin planning—immediately—how to deliver the relevant information to internal staff and stakeholders, as well as to customer groups, which includes the traveling public.

Internal Communications

Within the agency and among project stakeholders, methods for managing and disseminating information include the following:

- **Phone calls and emails**
  Important information on the nighttime construction project, such as location, alternate routes, detours, hours of operation and closure, as well as the contact information for the project, can either be delivered by phone calls to the relevant personnel at the site or can be e-mailed directly.
- **Discussions and meetings**
  Discussions and meetings are conducted among agency personnel to deliver information and the current status on traffic control, construction, design, field, and other issues. If construction work has an impact on access to certain facilities/main buildings, agencies should meet regularly to provide information about what will happen and the duration of activities.

External Communications

Information can be sent to the public in many different ways. It is crucial for agencies to adopt the most effective and suitable means to ensure the information is delivered effectively. Agencies and contractors should provide specific project information for the public, as well as respond to the public's day-to-day needs and concerns.

Following is a brief discussion of the essential elements of an effective external communication plan.

Table 9.1 Sample matrix for external communications planning.

Group	Public Meetings	Fliers	Mailings	Door to Door	Radio/TV	Website	Social Media	Telephone Hotline	Email	…
Road users										
Local businesses										
Patrons										
Emergency personnel										
Taxpayers										
Local government officials										
Politicians										
…										

External Communication Matrix

A useful tool when first starting external communications planning is to create a matrix (something like the one shown in Table 9.1).

The rows of the matrix could list each of the possible groups affected and the columns could list all the possible information dissemination methods to use. Notations are then made under each method that might constitute an appropriate communications match for reaching that group, depending on the activity at hand.

Resource

The FHWA has a more-comprehensive list of possible ways to communicate in *Work Zone Public Information and Outreach Strategies* (FHWA 2005a) at http://ops.fhwa.dot.gov/wz/info_and_outreach/sec2.htm#two6.

All communication items should be included in communication planning, without regard to who is ultimately responsible for implementation, in an effort to promote a one-team, one-vision, and one-voice concept. The communications plan ultimately must be tied to the project's activity schedule. Table 9.2 is a sample (or starter) template from WSDOT for developing an external communications plan that includes a column for when each activity occurs.

Table 9.2. Starter template for external communications planning (WSDOT 2005).

What	Who	How	When
With Stakeholders			
Identify stakeholders			
Conduct local agency briefings			
Determine future work anticipated or planned by local agencies			
With the Public			
Public involvement			
Project website			
STA contact with public			

Public Hearings/Meetings/Workshops

Prior to construction, the FHWA recommends organizing public hearings or meetings in a convenient location for community members who are affected by the nighttime construction activities. Other events may include groundbreaking ceremonies, fairs, school assemblies, tours, and informational workshops.

The purpose of these meetings is to update affected parties and resolve complaints, as well as give the affected parties an opening to gain knowledge about the project and convey information and concerns to the project partners. These events should be used to explain the reasons for night scheduling and to obtain comments and suggestions from the community.

Public hearings and meetings are considered important, particularly when it comes to nighttime construction. For example, construction noise that may be acceptable in daylight hours may be unacceptable at night. Therefore, if the public is fully informed about and prepared for the nighttime construction activity, negative public reaction may be mitigated.

Interaction with the public can be the determining factor in the success of a public information/outreach campaign. To ensure that information is communicated effectively and is responsive to the public's needs, it is the responsibility of the agency and contractors to obtain input regarding the nighttime construction activities.

Besides receiving current progress and any updates or changes in the alternate routes and detours during these events, individuals can sign up to receive information about the project via project social networking sites, email, or websites.

Some efforts that have been made by agencies include a series of workshops for the local businesses affected by the construction. For example, the Utah Department of Transportation (UDOT), through its I-15 CORE project, held a series of workshops to help businesses get information about the project and create strategies for success during construction. During public hearings, meetings, or workshops, the FHWA recommends that agencies deliver project information via video, as it is an efficient way to give the public a clearer view of the intended outcome of the work in progress.

Tip

An agency phone number and address should be provided to the public to use for submitting comments or complaints.

In the weeks preceding the actual start date of the construction, the public must be informed of what is going to happen, when it will occur, and how it is likely to affect specific locations.

Telephone Hotline

Agencies may implement a telephone hotline staffed by trained personnel who are knowledgeable about the nighttime construction activities. This should serve as a single point of contact for receiving community input as well as answering questions regarding the ongoing construction-related activities, such as construction schedules, lane or street closures, and transportation alternatives (NJDOT 2007b).

The hotline should be available 24 hours a day, seven days a week, and the number should be publicized extensively. In addition, it should be handicap accessible (such as telecommunications device for the deaf or TDD) and free, as well as accessible both pre-trip and en route.

An immediate response is preferable for all calls, although a voice mail option can be used. Tape-recorded messages can be used if the project information is updated frequently. Additionally, personal operators should be available for large projects or to return calls for questions that the taped message does not answer.

The hotline should also be used to publicize public meetings, survey information, and for the public to leave comments and suggestions.

Media Relations

Disseminating information about nighttime construction, such as nighttime schedule, alternate routes, closure times, and detours, should be publicized through the news media. Press releases are recommended, especially when the nighttime construction involves a route with a high traffic volume or that affects major businesses and properties (see Figure 9.3).

Key Take-Away

As shown in Figure 9.3, be sure to include:

- Warnings about nighttime construction.
- Lane closures, duration (time), and length of closure (days).
- Use of flaggers and traffic control measures.

The California DOT (Caltrans) found that newspaper articles were the most effective means of communicating with the public. The frequency of press releases depends on the size, duration, and impact of the project. The agency's public relations unit should be the point of contact to provide the information. (Faxes and email messages to selective distribution lists are common practices used by public relations departments to channel information to the press.)

pennsylvania
DEPARTMENT OF TRANSPORTATION

News for Immediate Release

Oct. 22, 2010

Nighttime Construction Next Week to Restrict Travel Though Route 202/ Route 63 Intersection in Montgomery County
Daytime lane and turn restrictions also will continue on both roads as part of Route 202 Parkway construction

King of Prussia - Motorists traveling through the intersection of Route 202 (DeKalb Pike) and Route 63 (Welsh Road) in Upper Gwynedd, Lower Gwynedd and Montgomery townships, Montgomery County may encounter congestion and delays for two nights next week for construction, the Pennsylvania Department of Transportation said today.

Crews will reduce both roads to one lane in each direction at the intersection Sunday, Monday and Tuesday nights (Oct. 24-26) from 7 p.m. to 5 a.m. the following morning for installation of drainage pipes and inlets. The night work will temporarily eliminate all turn lanes at the intersection, requiring motorists making left or right turns to do so from the single through lane.

Turn restrictions – which may cause periodic backups -- also will remain in place around-the-clock during the remainder of the week at the Route 202-Route 63 intersection, where three of the four left turn lanes that normally are available have been eliminated or shortened. Restricted left turn moves are in place on Route 202 south and on Route 63 east and west during construction to widen the intersection.

Drivers will also encounter periodic traffic stoppages of up to 15 minutes on Route 63 (Welsh Road) between Stump Road and Route 202 (DeKalb Pike) on Monday through Friday (Oct. 25-29) from 9 a.m. to 3 p.m. for the widening of Route 63 where it will intersect with the new Route 202 Parkway.

Flaggers will continue to direct an alternating single lane of northbound or southbound traffic through work areas on Route 202 (DeKalb Pike) between Sumneytown Pike and Route 63 (Welsh Road) on Monday through Friday (Oct. 25-29) from 9 a.m. to 3 p.m.

These activities are part of the $17.7 million project to widen and improve two miles of Route 202 (DeKalb Pike) from Swedesford Road to Route 309, and to connect Route 202 (DeKalb Pike) with the new Route 202 Parkway, which also is under construction.

Figure 9.3. Local news coverage on a nighttime construction (Pennsylvania DOT).

Consequently, another option is paid advertising. This may be appropriate for major changes or closures on Interstates or other major routes. For example, the North Dakota DOT (NDOT) used paid advertising on the I-29 project in Fargo. The Kentucky Transportation Cabinet (KYTC), on its I-64 weekend project, used newspaper advertisements as one of its communication tools to disseminate project information to the public. Advertisements can provide the audience with a brief idea on project progress and any other issues pertaining to the work.

Finally, highway advisory radio (HAR) can be helpful, given that it broadcasts nonstop traffic information, 24 hours a day. However, due to Federal Communications Commission (FCC) regulations, the broadcasts have a very restricted range. Therefore, this type of communications method is recommended for travelers in a very small area.

Contact Person/Communications Team

To ensure proper and accurate information is distributed and public inquiries are addressed properly, it is imperative for agencies to have a contact person or a communications team to support the nighttime construction. These professionals should handle all communications activities, including the press, and be responsible to obtain accurate information from the contractor to disseminate to the public.

Tip

Be sure to have a knowledgeable person/team in charge and available at all times to provide accurate construction information to the media and the public. For large projects or long duration projects this contact/team must be available 24/7.

Tools for Disseminating Information

Agencies will consider the use of many different tools to disseminate information regarding nighttime construction activities.

Electronic Information Dissemination

The methods of communication are quickly changing as more and more people access information using electronic resources. This includes information through computer sources, such as websites and social media, as well as television or radio commercials.

Websites

Websites and/or blogs are an excellent means of providing information about nighttime construction. According to the FHWA, websites can be used in two different ways to provide information about projects. For larger-scale projects that involve an entire state, district, or geographic region, it is essential to provide relevant information on closures and alternate routes for travelers. For smaller projects, where information does not change frequently or little project information is of interest to the public, websites may also be beneficial.

An example of a reconstruction project website, developed by the Texas DOT (TxDOT), that is attractive, informative, creative, and user friendly is shown in Figure 9.4.

For larger complex projects, the standard practice is to have a website dedicated solely to the project. The information within this type of website may be either static or real-time information. Typical information would include text, traffic camera images, average travel times between points, photographs, maps, and links to other sources of information. The information on the website should be updated at least weekly and can be made interactive.

Figure 9.4. Sample project website developed by TxDOT.

An example of a popular website is the 511 Travel Information website for Iowa at www.511ia.org/. In July 2000, the FCC assigned 511 for nationwide access to travel information services. It is an automated traveler information system that helps commuters and travelers access information regarding weather-related road conditions, construction, and congestion, via the web or phone, 24 hours a day, 7 days a week.

Agencies usually place the 511 logo on signs along the roadway as shown in Figure 9.5.

Figure 9.5. The 511 travel information logo (FHWA 2005b).

The logo informs drivers that 511 service is available in an area. As of March 2005, 511 systems were operational in all or parts of 23 states, providing access to 511 services to almost 30 percent of the nation's population (FHWA 2005b). The 511 system was found to be easily accessible, as calls can be made from almost anywhere at any time.

The 511 websites contain information about projects such as lane closures, ramp/loop closures, and roadway closures that impact traffic and travel conditions.

Social Networking Sites (Facebook and Twitter)

Social networking sites have experienced extraordinary popularity. To reach out to the networking portion of the public, agencies should make full use of social networking sites, such as Facebook and Twitter.

Individuals are free to explore these sites, and agencies may conduct interactive sessions with individuals for question and answer (Q&A) sessions about the nighttime construction activities. For example, TxDOT has used social media (Twitter) in its San Antonio District to deploy construction information rapidly at http://twitter.com/txdotsanantonio.

The Arizona Department of Transportation (ADOT) utilizes Twitter and Facebook to provide real-time information about detours and restrictions, notices when there are travel delays and construction impacts, and alerts with holiday travel information, construction schedule changes, and completed major milestones for U.S. Highway 93 roadwork.

Commercials (Radio and Television)

Some agencies, such as the KYTC on its I-64 project, used creative radio commercials to describe some of the consequences of being stuck on the Interstate during weekday construction when it was done instead of the weekend closures. These commercials put a positive spin on the decision to avoid the heaviest traffic by performing the construction over the weekend.

Key Take-Away

Information gathered on the progress or changes that occur during nighttime construction needs to be posted immediately on the project's public website and social networking sites.

Email

The use of email message lists is one of the simplest ways to communicate and the primary cost is just the time to write the message that goes to multiple individuals. Once a list of email addresses is obtained (from public hearings or other sources) mass email can be sent out with targeted information about the nighttime work activities and the effect on traffic patterns.

KYTC recommends that email list services send traffic and construction information out at around 6 a.m. and before 4 p.m. to the public. When users register for the KYTC service, they can select a list of roads of interest and receive specific information regarding those roads (Hancher and Taylor 2001).

Some agencies provide on their official websites a sign-up form for email alerts regarding a road construction project. Users who sign up may receive a variety of information, such as work-zone activity and traffic delays, lane closures, and incident/crash information. The information can also be sent to all types of personal digital/data assistant (PDA) devices.

Printed Materials

Fliers, brochures, pamphlets, fact sheets, maps, and newsletters are other common methods used to disseminate project information. When using the newsletter as a public information and outreach strategy, it is crucial to set a consistent timeframe for producing new editions. Establishing a consistent timeframe helps ensure that producing the newsletter does not "fall through the cracks" and lets readers know when to look for the next issue (FHWA 2005a). Frequent updates are necessary if project details are constantly changing.

Printed materials can be hand delivered; mailed; placed for pickup at stores, welcome centers, truck stops, and the like; placed in newspapers; or distributed door to door. In addition, the materials can be posted as a downloadable document on the project or agency's website.

These materials should be brief but loaded with relevant information, such as upcoming project phases, events, and other important work-zone details, together with the contact person for more information. The critical parts are advance notification and information regarding nighttime construction and how it will have an impact on travel. Figure 9.6 is an example of nighttime construction information in the form of a "special notice."

Project "brand," which may include eye-catching graphics, project logos, photographs, and maps, can help make printed materials an effective medium for distributing the information and for promoting project websites, telephone hotlines, and other media. Printed items should be distributed to the public frequently, or as needed, and they can be mailed or sent electronically using email to individuals who have signed up to receive information.

THE CITY OF SAN DIEGO

SPECIAL NOTICE

Night Time Construction Activities Along 54th Street Between El Cajon Boulevard and University Avenue Are Underway

October 28, 2008

The construction of the Otay II Pipeline Replacement Project is underway. The Otay II Pipeline will increase water capacity and improve water delivery system throughout San Diego. The construction started in April 2008 and will be completed by December 2010.

As a part of the work, construction crews will excavate the roadway, install new 42-inch steel pipe, backfill the trench and re-pave the roadway along the project alignment, 54th Street between El Cajon Boulevard and Redwood Street. Although the majority of construction work will be done during daytime working hours, a segment of the project on 54th Street between El Cajon Boulevard and University Avenue will have to be constructed during night time due to traffic volume and safety issues. Work on this segment started on October 19 and may continue on and off into 2009. There will be occasional night work for the connection of the existing pipelines to the new installed pipeline at intersection of 54th Street with Trojan Avenue in late December 2008, the intersection of 54th and El Cajon Boulevard and Redwood Street and also on Easy Street in winter of 2009. During these connections the contractor will be working 24 hrs shifts as long as three days continuously in order to assure no interruption to City wide water supplies. The City will provide more detail information about these connections and the construction activities at these locations later on. There will be no disruption of water services during entire construction and water services will be maintained all the time.

The night time construction activities on 54th Street between El Cajon Boulevard and University Avenue will be between the hours of 8:00 p.m. and 6:00 a.m., Sunday through Thursday. Normal working hours will be Monday through Friday, 8:30 a.m. to 3:30 p.m.

Measures will be implemented to ensure pedestrian safety and continued vehicle access for impacted residents on 54th Street and all construction areas during the construction period.

Thank you for your patience while the City of San Diego completes the construction of this important project. This project is part of the City's overall water delivery system improvement program implemented to provide safe and reliable water for San Diego. The total cost of the project is estimated at $13 million and will be funded by water rates and revenue bonds.

If you would like more information about this project, call the Public Information Line at 619-533-4679 or Bobak Madgedi at 619-533-5241. If you'd like to receive email updates regarding this project, please send an email to engineering@sandiego.gov.

This information is available in alternative formats upon request.

Project Implementation and Technical Services
Engineering and Capital Projects • 1010 Second Avenue, Suite 1200 • San Diego, CA 92101-4905
Tel (619) 533-4679

Figure 9.6. Sample information regarding nighttime construction activities in a "special notice" (City of San Diego 2008).

Fact sheets (Figure 9.7) or brochures, as well as fliers, should contain the following basic project information:

- Project overview.
- Reasons for improvement.
- Description of project phases with color-coding related to a map.
- Impacts to traffic.


OPTIMIZING PERFORMANCE

MOBILITY & SAFETY

MAKING WORK ZONES WORK BETTER

U.S. Department of Transportation

Federal Highway Administration

Oregon's QuickFax Service

JULY 2000

Oregon Department of Transportation

1 FACT SHEET

Truckers Get Immediate Information on Traffic Delays and Closures

Commercial truckers can get up-to-the-minute information on closures and traffic delays on Oregon State highways through the Oregon Department of Transportation's (ODOT) QuickFax service. Bulletins are faxed to approximately 154 trucking companies and 30 truck stops to inform them of immediate traffic delays related to incidents or weather.

This system was developed through ODOT's public affairs department after a 1997 flood shut down many of Oregon's major highways. "We were trying to keep the media informed about the road closures and it would take about three hours to fax the information out to all who needed it," said Dave Davis, ODOT Region 2 Public Affairs. He said that by the time they got the information to all the media it was already outdated. Then U.S. West started a broadcast fax system, which delivers 50 faxes at once. This system cut notification time from 3 hours to 20 minutes.

Information Helps Truckers Plan Their Trips

"It seemed natural to develop this system for the trucking industry. We contacted the Oregon Trucking Association and other organizations to ask them to subscribe to the service," said Davis. Initially the service had about 50 trucking companies and a few truck stops as subscribers, but the program has now become a staple of truckers in the Oregon area. Trucking companies call in and get on the broadcast fax list. When incidents and road closures occur, ODOT then sends an alert to QuickFax subscribers. The service's subscriber base reaches truck stops as far away as Virginia, Nebraska, Wyoming, and California, so truckers heading into Oregon from those locations can have advance warning of any long-term road closures.

Figure 9.7. Fact sheet for a road project in Oregon (FHWA 2001).

- Detours and alternate routes for travelers/regular traffic.
- Sources of up-to-date project information.
- A message from the city/authority (governor/mayor).

Other Methods

Establishing collaboration with local agencies is another effective way to disseminate information. Short broadcasts using public access channels, local news, or radio can be beneficial to reach a larger audience and surrounding areas. If necessary, presentations and tours of the work may be arranged in an effort to reach public and community groups.

The Automated Work Zone Information Systems (AWIS) is another way to manage demand in and around highway construction work zones. According to the FHWA publication *Managing Demand through Travel Information Services,* AWIS typically gathers real-time traffic information in work zones using radar sensors and video cameras located along the roadway (FHWA 2005b).

These data are used to determine, automatically or by operations personnel, traffic speeds, backup locations, and queue lengths, as well as the location of incidents causing traffic to slow or stop. Together with other data, such as work-zone schedules, information is then provided to travelers about road/lane closures, times of construction, travel time through work zones, incident information and warnings, and detour information.

Transportation agencies may consider establishing an information center for large, long-term work zones. The information center serves as a contact point for travelers, as well as a medium to disseminate information. The FHWA recommends that the project information center be located in an area with high foot traffic in the general vicinity of the work-zone location (FHWA 2005b).

As guidance, the FHWA (2005a) has developed a table of comparisons based on different types of communication strategies that can be implemented for work-zone public information and outreach programs. Table 9.3 summarizes and compares different types of communication strategies across numerous aspects: communications strategy, target audience, benefits of different strategies, issues pertaining to each strategy, applicability, and timing, as well as the strategies' relative costs for nighttime projects.

The information in Table 9.3 needs to be taken into consideration when planning to disseminate project information. The relative costs are presented as low/medium/high, given that actual costs depend on the scope of the strategy and location and will vary across different regions of the country.

Conclusions

Effective communications are essential in making nighttime construction work proceed smoothly with fewer social impacts. Many communication methods are available to disseminate information regarding construction activities. All of the communication methods listed in Table 9.1 (as well as many others) may be used for nighttime construction and Table 9.3 presents an effectiveness evaluation of multiple methods.

Agencies should keep the public informed about project location, duration, type of work, and benefits of the project. Information must be correct, as credibility is affected if a message is inaccurate.

Information may be provided to the local media (e.g., newspaper, television, and radio) in the form of press releases in advance of the start of night work. Frequently, local stations will include information about planned and active closures in their regularly-scheduled traffic-monitoring broadcasts.

Today, information can be disseminated easily and rapidly through the use of electronic tools, such as websites, social networking sites, email messages, and messaging signs placed on site to reach targeted audiences. Still, pamphlets, newsletters, and public service announcements are helpful to ensure that the surrounding community receives current, reliable, and updated information regarding the nighttime construction.

Table 9.3. Major characteristics of communication strategies (FHWA 2005a).

Strategy	Primary Target Audience	Benefits	Issues	Timing	Relative Cost to Project
Websites	• Pre-trip travelers • Most other audiences	• Access to real-time information • Ability to access all project-related materials in one place • May be easy to update	• Target audience needs to be aware of the website • May not reach the entire target audience (excludes people without an Internet connection) • Information needs to be current and accurate • Cost will vary based on complexity of website • May need to create mechanisms to collect data/ information to feed the site	• Pre-construction • Construction • Post-construction	Low/ medium
Email alerts	• Pre-trip travelers • En route travelers • Commuters • Commercial drivers	• Low cost • Can reach many people at one time	• Audience is limited to those people who sign up for the service • Need to determine criteria for when to send alerts	• Construction	Low
Brochures/ fliers/ factsheets/ newsletters	• Local travelers • Commuters • Commercial drivers • Residents	• Low cost • Easy to distribute	• Information can become stale quickly • Often targets local motorists only • Needs to be designed in a manner that makes drivers want to read the information	• Pre-construction • Construction • Post-construction	Low/ medium
Public meetings/ task forces/ workshops/ events	• Local travelers • Major trip generators • Residents • Businesses • Public officials • Major employers • Local agencies	• Good exposure to the public • Gives agency a chance to raise credibility with the public • Gives public a chance to voice its concerns	• Need to make sure the right audience is at the events • Need to be wary of making "empty promises"	• Pre-construction • Construction	Low

(continued on next page)

Table 9.3. (Continued)

Strategy	Primary Target Audience	Benefits	Issues	Timing	Relative Cost to Project
Paid newspaper advertising	• Local travelers (pre-trip) • Commercial drivers (pre-trip) • Major trip generators • Residents and small businesses	• Can reach many people at one time • The same ad can be used in many different newspapers • Agency controls the content and timing of the message	• May only target local motorists • Newspaper readers may skip over ads • Declining readership of print media	• Pre-construction • Construction • Post-construction	Medium/ high
Newspaper articles	• All local audiences	• Can reach many people at one time	• May only target local motorists • Project may not be portrayed favorably • Coverage more likely for major projects	• Pre-construction • Construction • Post-construction	Low
Paid TV advertising	• Pre-trip travelers • Local travelers • In rare cases, non-local travelers	• Can reach many people at one time • Agency controls the content and timing of the message	• May only target local motorists	• Pre-construction • Construction • Post-construction	Medium/ high
TV traffic news	• Pre-trip travelers • Local travelers	• Can reach many people at one time • Little to no cost	• May only target local motorists • Coverage more likely for major projects	• Construction	Low
Paid radio advertising	• Pre-trip travelers • En route drivers	• Can reach many people at one time • Agency controls the content and timing of the message • Targets people who are most likely to use the information	• May only target local motorists	• Pre-construction • Construction • Post-construction	Medium/ high
Radio traffic news	• Pre-trip travelers • Local travelers	• Can reach a lot of people at one time • Little to no cost • Targets people who are likely to use the information	• May only target local motorists • Coverage more likely for major projects	• Construction	Low

Strategy	Primary Target Audience	Benefits	Issues	Timing	Relative Cost to Project
Maps	• Drivers, pre-trip and en route	• Low cost • Can post online and have available in hard copy	• May only reach a limited audience, depending on how they are disseminated	• Construction	Low
Employee newsletters	• Major employers	• Innovative way of reaching commuters	• Need to ensure information is accurate • Need to target the appropriate employers	• Pre-construction • Construction	Low
CB radio network	• Truck drivers	• Reaches the truck driving community • Provides information to truck drivers who may be coming from out of the area	• Users need to have access to CB • Messages need to be worded in a manner that makes drivers listen • Need criteria for when to disseminate messages	• Construction	Low
Billboards	• Drivers en route	• Provides information directly to motorists affected by the project • Can refer motorists to other sources of information	• Can only provide a limited amount of information • Information needs to be current • May be better for longer term projects	• Pre-construction • Construction	Medium
Information center or kiosk	• All audiences	• Provides direct access to information and people to talk to about the project • May reach non-local drivers	• Needs to be located close to project area in an easy to access location • Information centers need to be staffed • Information needs to be current	• Pre-construction • Construction	Low/ medium/ high
Project hotline/ 511 System	• Pre-trip travelers • Drivers en route	• Information can be accessed whenever it is needed • Can allow motorists to provide feedback via recorded message • May be easy to update	• Information needs to be current • Audience needs to be aware of the hotline number • 511 is not available in all areas	• Construction	Low/ medium
Dynamic message signs (DMSs)	• Drivers en route	• Provides information directly to motorists affected by the project • Can provide detour information	• Messages need to be easy to read • Signs need to be placed appropriately • Information should be useful and accurate	• Construction	Low/ medium/ high

(continued on next page)

Table 9.3. (Continued)

Strategy	Primary Target Audience	Benefits	Issues	Timing	Relative Cost to Project
Highway advisory radio (HAR)	• Drivers en route	• Easy to access • Provides information directly to motorists	• Motorists may not be aware of HAR • Information needs to be current • Should only be used when there is information to give • Limited range	• Construction	Low
Press kit	• Media outlets	• Allows consistent message to be given to the media • Helps develop positive relationship with media	• Should be made available to all types of media • Information needs to be in a format that makes it easy to reuse for articles, ads, etc.	• Pre-construction • Construction • Post-construction	Low/ medium
Business survival kit	• All businesses	• Allows consistent message to be given to businesses • Helps develop positive relationship with affected businesses	• Needs to target the appropriate businesses • Needs to not minimize the importance of businesses' needs during the project	• Pre-construction • Construction	Low/ medium
Branding	• All audiences	• Helps convey a consistent message and image on all project materials • Makes project materials easily recognizable	• Should be easily understood and easy to remember	• Pre-construction • Construction • Post-construction	Medium
Videos	• All audiences	• Can illustrate the before, during, and after of the project • Can give viewers close-up details about the project • Can be shown in various locations (schools, public meetings, information centers, etc.) • Helps convey a consistent message about the project	• Quality videos can be expensive to produce • Information can quickly become stale • May require a lot of up front planning (script writing, storyboarding, etc.)	• Pre-construction • Construction • Post-construction	Medium/ high

CHAPTER 10

Interactions

Because of transportation-corridor congestion, nighttime construction is becoming standard STA practice. This Guidebook presents discussion and practice concerning both the real and perceived factors and risks that influence the decision to conduct nighttime work and can have an impact on the successful accomplishment of a nighttime project.

The factors considered in nighttime construction decisions and planning interact with each other, given that the risks associated with nighttime construction activities are not mitigated exclusively or monitored by only one method. The gray-shaded squares in Table 10.1 denote areas of interaction between the factors.

These interactions need to be understood and considered when planning nighttime projects. Therefore, this chapter summarizes some of the interactions.

Illumination Interactions

Good illumination is essential for all nighttime construction and maintenance activities. Moreover, illumination needs to be designed properly so it does not become a nuisance. Care is needed to provide adequate illumination without having a negative impact on the public; this includes glare control for motorists and light intrusion into residences.

Proper illumination improves productivity and quality. There is an added expense for providing this illumination for night work. The transportation agency may or may not pay directly for the cost of providing lighting, but the contractor will include this expense as part of the project cost.

Designers and others need to take lighting into account in project development. Furthermore, installation of permanent lighting as soon as possible can help reduce the additional costs of temporary lighting.

Finally, the ability of workers and the public to see has a direct impact on safety. Good vision requires good illumination of the work zone.

Nuisances Interactions

Sounds that would not be noticed while working during the day can be a nuisance during nighttime construction activities, when background noise is reduced. This Guidebook presents a number of nuisance mitigation measures. Interactions occur between nuisances and the productivity, costs, and communications factors.

Table 10.1. Interactions between factors or nighttime construction risks.

	Illumination	Nuisances	Productivity	Quality	Cost	Safety	Communications
Illumination							
Nuisances							
Productivity							
Quality							
Cost							
Safety							
Communications							

If an activity includes a nuisance due to location, that activity may be restricted during nighttime hours, having an impact on worker productivity and the project. For this reason, transportation agencies and contractors need to plan ahead and address these activities prior to execution. This may even mean that construction methods will need to be changed.

In addition, costs are associated with nuisance mitigation measures. These costs that are incurred on the project may or may not be paid for directly by the transportation agency.

Finally, communications are needed both between project personnel and with the public to address any nuisances created by project activities.

Productivity Interactions

Productivity impacts interact with the quality, cost, and safety factors. While possibly increasing productivity, a worker working too quickly, not wanting to work during nighttime hours, can affect the quality of the project. Similarly, working too slowly, perhaps because of poor lighting, may decrease the quality of the project.

Low productivity results in longer hours, which could result in increased costs to the project.

Finally, if workers feel unsafe and are constantly looking over their shoulders and not concentrating, there will be a decrease in productivity.

Quality Interactions

There are interactions between quality and the cost and communications factors. On projects with incentive/disincentive quality clauses for pay items, the cost to the project may increase or decrease depending on the quality achieved during nighttime activities.

In addition, transportation agencies and contractors need to have clear communications regarding the expectations of the quality of work expected. However, this is not necessarily unique to nighttime construction.

Cost Interactions

For nighttime construction, there is a cost interaction with every other factor. Some of these interactions are positive, meaning reduced costs, such as less road user time, fewer accidents, and possibly less time that materials are stuck in traffic, which could mean better quality. Some of the cost implications and interactions are negative, such as additional lighting requirements for quality and safety.

Safety Interactions

Safety interactions occur with the illumination, productivity, cost and communications factors. One key to nighttime safety is lighting.

Workers are more productive if they know traffic hazards have been considered and positive measures instituted to keep vehicles out of the work zone.

Additional attention to and measures for ensuring both worker and public safety during nighttime construction comes with an associated cost, which may be offset given many of the advantages of conducting the work at night.

Finally, communications about nighttime construction activities by STAs to the public can aid in ensuring a safe work zone.

Communications Interactions

There is an interaction between communications and the nuisances, safety, quality, and cost factors with nighttime construction.

Communications are imperative to address nuisance issues with the public as well as the safety of all those involved in the project. Communications within the STA are needed to ensure proper quality and cost information throughout the project development process for estimating and design.

Summary

None of these factors or risks of nighttime construction activities presented in this Guidebook act singularly in a silo; they have significant effects on each other. STA personnel need to understand these interactions when developing, planning, and executing nighttime construction projects. Design consideration that can be changed early in project development must consider when the work activities will be conducted. Project design has a considerable impact on all of these aspects.

CHAPTER 11

Summary for Implementation and Keys to Success

A 2001 review of 789 work zones in 13 states during summer months found that 33 percent of the projects reported work-zone activities or lane closures primarily at night (Wunderlich and Hardesty 2003). An additional nine percent reported continuous work—both day and night.

The duration of the night work closures reviewed clustered between 7 and 9 hours. Such durations indicate that night construction work is usually conducted all night rather than just during one portion of the hours of darkness.

This review also found that two-thirds of all resurfacing/paving activities were conducted at night but only one-third of the bridge work.

In certain areas, transportation agencies are conducting all construction work at night. Even with these experiences, STAs still have misgivings about possible negative effects of night work.

While there are disadvantages to working at night, a careful examination of the research and data supplied by STAs found that the perceived disadvantages are limited and can be controlled through good planning. In addition, the advantages of construction activities at night often outweigh the perceived disadvantages.

Disadvantages and Advantages

Table 11.1 shows a number of perceived disadvantages and advantages to nighttime construction. Some are within the control of the transportation agency while others are outside direct agency control.

The perceived disadvantages were, in many cases, determined to be unfounded by research, as indicated in this Guidebook. A number of very effective mitigation measures can be used to address the actual disadvantages.

Frequent criticism about nighttime construction and the many perceived disadvantages are repeatedly recited; however, when examining the issues carefully, the difference between day and nighttime construction is not significant in terms of cost, productivity, quality, or safety.

Good illumination and better traffic control are needed. Good planning can mitigate or limit the impact of all perceived disadvantages of nighttime construction. Planning needs to start during the very earliest stages of project development or, at the latest, when making the decision to conduct nighttime construction. This decision should always be made as early as possible in project development, as design decisions affect successful execution of night work.

Lighting is critical for successful nighttime projects, and it needs to be quality lighting, which will add costs. Residential neighborhoods may find construction during nighttime hours more

Table 11.1. Disadvantages, mitigation of disadvantages, and advantages of nighttime construction (Elrahman 2008).

Factor	Disadvantage	Mitigation	Advantage
Illumination	Need to provide good illumination	Require an illumination plan and good lighting	
Nuisances	Local ordinance may restrict work at night	Require a noise control plan and limit equipment noise	
	Can cause noise, vibration, light, and other disturbances	Use new equipment, monitor work-zone noise	
Productivity	Increased set up and removal time of traffic control and lighting	Detailed traffic control planning	Increased flexibility in work zone due to less traffic interference
	Reduced visibility of work area	Provide proper illumination	Less traffic interference and longer work shifts have positive effect on productivity
	A perception that there is lower productivity	Need more detailed activity planning	Allow more lanes to be closed temporarily
	Longer equipment repair time during breakdowns	Use newer equipment, repair parts available, or provide backup equipment if schedule is critical	Longer duration work periods
	Personnel scheduling may be more difficult	Careful scheduling of activities and good communication	Project duration decreased
	Restrictions may be imposed by unions or material suppliers	Work with unions to understand restrictions and plan ahead with material suppliers to ensure adequate supply	
	Biological clock factors, loss of sleep	The Strategic Highway Research Program (SHRP 2) project R03: Identifying and Reducing Worker, Inspector, and Manager Fatigue in Rapid Renewal Environments is exploring these issues	
	Employee satisfaction		
Quality	Work quality may be affected negatively	Provide good lighting based on work activities	Cooler temperatures can enhance paving work
	Less aesthetically pleasing products		
Cost	Need enhanced traffic control	Good traffic control planning	Decreased impact on businesses
	Need artificial illumination	Good illumination planning	Decreased impact on traffic
	Impact on trucking industry	Communication	
	Material delivery cost may be higher		Decreased traffic interference
	Premium pay		
Safety	More traffic accidents	Good traffic control	Lower traffic demand
	More work accidents	Special training for nighttime workforce	More conscious of safety practices
	Lower levels of speed enforcement		Traffic delays decreased
	Driver fatigue and impairment	Well-illuminated work zones and traffic control	
	Worker's perception of danger	Better training required	
Communication	Delayed project decisions	Project staff need to have authority to make decisions in reasonable timeframes (especially at night, rather than waiting until the next day)	

110 A Guidebook for Nighttime Construction: Impacts on Safety, Quality, and Productivity

Table 11.2. Keys to success for each of the primary areas of risk.

Risk Area	Keys to Success
Illumination	Provide proper illumination through planning and design to ensure productivity, quality, and safety.
Nuisances	Write nuisance control measures into the project specifications.
Productivity	Detailed planning and scheduling, with extra labor training, improve productivity.
Quality	Specify the desired quality; some activities benefit from cooler temperatures and less traffic congestion.
Cost	Decrease lighting costs by designing and phasing the project so that permanent lighting is installed early; consider the additional costs of lighting, nuisance mitigation, and traffic control in the estimate, but also consider productivity impacts of less congestion and longer work periods.
Safety	Priority one on every jobsite is safety, for the workers and the public; night work requires detailed traffic control planning.
Communications	Provide honest, timely information to the public regarding the project; authorize project personnel to make decisions by providing them with clear communication lines to obtain information.

of a nuisance, but mitigation measures can limit the impact of the nuisances. The nuisance mitigation measures should be written into the project special provisions.

Beyond the few true disadvantages, the advantages are clearly apparent and careful planning can mitigate the disadvantages. The primary advantage of nighttime construction is less traffic interference with construction activities, which usually translates into better production and quality.

Key Points for Success

Research has shown that construction projects are more successful when there are greater levels of planning (Construction Industry Institute 1996). This means starting early in the project development process.

Nighttime construction requires a detailed illumination plan, careful work planning and sequencing, traffic control, and nuisance mitigation planning. Planning needs to begin during the earliest phase of project development. Design decisions have a tremendous impact on the success of nighttime projects. Therefore, designers must be part of the construction planning team. Table 11.2 summarizes the keys to success for each of the primary areas of risk.

References

Abraham, D. M., J. J. Spadaccini, B. B. Burgess, L. R. Miller, and V. Valentin. 2007. *Evaluating and Enhancing the Safety of Nighttime Construction Projects.* Joint Transportation Research Program. Indiana Department of Transportation and Purdue University. West Lafayette, Indiana. October 2007. http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1707&context=jtrp&sei-redir=1#search=%22FHWA%2FIN%2FJTRP-2007%2F14%22.

Åkerstedt, T. 2007. Altered Sleep/Wake Patterns and Mental Performance. *Physiology & Behavior.* 90(2-3): 209-218. February 2007.

Al-Kaisy, A., and K. Nassar. 2002. Nighttime Construction Issues Revisited. Presented at 82nd Annual Meeting of the Transportation Research Board, Washington, D.C., January 2002.

———. 2003. Nighttime Construction Issues Revisited. *Proceedings of the 82nd Annual Meeting of the Transportation Research Board.* January 2003. CD-ROM.

———. 2005. Nighttime Construction Issues Revisited. *Journal of Construction Research.* 6(1):139-156.

American National Standards Institute/International Safety Equipment Association (ANSI/ISEA). 2004. *High-Visibility Garment Standard, ANSI-107-2004.*

———. 2006. *American National Standard for High-Visibility Public Safety Vests, 207-2006.*

Anderson, S., K. Molenaar, and C. Schexnayder. 2007. NCHRP Report 574: *Guidance for Cost Estimation and Management for Highway Projects During Planning, Programming, and Preconstruction.* Transportation Research Board of the National Academies, Washington, D.C.

Anderson, S. and Schexnayder, C. J. 2009. NCHRP Project 20-68A, "Best Practices in Accelerated Construction Techniques." Scan 07-02. Washington, DC: Transportation Research Board. http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-68A_07-02.pdf.

Arditi, D. 1985. Construction Productivity Improvement. *Journal of Construction Engineering and Management.* American Society of Civil Engineers. 111(1):1-14. March 1985.

Arditi, D., M. Ayrancioglu, and J. Shi. 2004. Effectiveness of Safety Vests in Nighttime Highway Construction. *Journal of Transportation Engineering.* American Society of Civil Engineers.130(6):725-732.

Arditi, D., D. E. Lee, and G. Polat. 2007. Fatal Accidents in Nighttime vs. Daytime Highway Construction Work Zones. *Journal of Safety Research.* 38:399-405.

Atkinson, G., A. Coldwells, T. Reilly, and J. Waterhouse. 1993. A Comparison of Circadian Rhythms in Work Performance Between Physically Active and Inactive Subjects. *Ergonomics.* 36(1-3):273-281.

Business and Legal Resources (BLR). 2011. *Spanish Worker Training.* BLR Employee Training Center. http://training.blr.com/employee-training-topics/Spanish-Worker-Training

Boddy, R., R. Frantz, and B. Poe-Tierney. 1986. The Marginal Productivity Theory: Production Line and Machine Level by Work-Shift and Time of Day. *Journal of Behavioral Economics.* 15:1-23.

Bryden, James E., and Douglas J. Mace. 2002a. *NCHRP Report 475: A Procedure for Assessing and Planning Nighttime Highway Construction and Maintenance.*. TRB, National Research Council, Washington, D.C.. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_475.pdf.

———. 2002b. *Guidelines for Design and Operation of Nighttime Traffic Control for Highway Maintenance and Construction.* NCHRP Report 476. TRB, National Research Council, Washington, D.C.. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_476.pdf

Bryden, J. E. 2003. *Traffic Control Handbook for Mobile Operations at Night: Guidelines for Construction, Maintenance and Utility Operations.* U.S. Department of Transportation. Federal Highway Administration. Washington, DC. August 2003. http://www.dot.state.il.us/blr/l023.pdf

———. 2004. *Working Safely at Night.* Presentation at 2004 American Road & Transportation Builders Association (ARTBA) Work Zone Safety Conference & Exhibition. November 2004. Baltimore, Maryland. www.workzonesafety.org/files/documents/news_events/wz_conference_2004/night_work.pdf.

Bureau of Labor Statistics. *Census of Fatal Occupational Injuries (CFOI) - Current and Revised Data.* US Department of Labor. http://www.bls.gov/iif/oshcfoi1.htm

Caldwell, J. A., J. L. Caldwell, and R. M. Schmidt. 2008. Alertness Management Strategies for Operational Contexts. *Sleep Medicine Reviews.* 12(4):257-273.

Central Federal Lands Highway Division (CFLHD). 2008. *CFLHD Engineer's Estimate Manual.* US Department of Transportation. Federal Highway Administration. February 2008. 24 pp.

City of San Diego. 2008. SPECIAL NOTICE—Night Time Construction Activities Along 54th Street Between El Cajon Boulevard and University Avenue Are Underway. Project Implementation and Technical Services. www.sandiego.gov/engineering-cip/projectsprograms/pdf/otaynight.pdf.

Colbert, D. A. 2003. *Productivity and Safety Implications of Night-Time Construction Operations.* Independent Research Study Report. Purdue University. West Lafayette, Indiana May 2003.

CII. 1993. *Zero Injury Techniques.* RS32-1. Construction Industry Institute. Austin, Texas.

———. 1996. *PDRI: Project Definition Rating Index: Industrial Projects.* 3rd Edition, Implementation Resource 113-2. CII. Austin, Texas. December 1996.

Cottrell, B. H., Jr. 1999. *Improving Night Work Zone Traffic Control.* Virginia Transportation Research Council. Charlottesville, Virginia. August 1999. http://virginiadot.org/vtrc/main/online_reports/pdf/00-r8.pdf

Daan, S., D. G. Beersma, and A. A. Borbély. 1984. Timing of Human Sleep: Recovery Process Gated by a Circadian Pacemaker. *American Journal of Physiology.* 246(2):R161-R183.

Dames & Moore. 1977. *Report of the 1977 Symposium on Highway Construction Noise.* Cranford, New Jersey.

Daniel, J., K. Dixon, and D. Jared. 2000. Analysis of Fatal Crashes in Georgia Work Zones. *Transportation Research Record: Journal of the Transportation Research Board, No. 1715.* TRB, National Research Council, Washington, D.C., pp. 18–23.

Dijk, D. J., and C. A. Czeisler. 1994. Paradoxical Timing of the Circadian Rhythm of Sleep Propensity Serves to Consolidate Sleep and Wakefulness in Humans. *Neuroscience Letters.* 166(1):63-68.

Douglas, K. D., and S. B. Park. 2003. *Selection Criteria for Using Night-Time Construction and Maintenance Operations.* Report SPR 322. Oregon State University. Corvallis, Oregon. May 2003.

Duffy, J. F., and C. A. Czeisler. 2009. Effect of Light on Human Circadian Physiology. *Sleep Medicine Clinics.* 4(2):165-177.

Dunston, P. S., B. M. Savage, and F. L. Mannering. 2000. Weekend Closure for Construction of Asphalt Overlay on Urban Highway. *Journal of Construction Engineering and Management.* American Society of Civil Engineers. 126(4):313-319.

El-Rayes, K., and K. Hyari. 2005a. CONLIGHT: Lighting Design Model for Nighttime Highway Construction. *Journal of Construction Engineering and Management.* American Society of Civil Engineers. 131(4):467-476.

———. 2005b. Optimal Lighting Arrangements for Nighttime Highway Construction Projects. *Journal of Construction Engineering and Management.* American Society of Civil Engineers. 131(12):1292-1300.

El-Rayes, K., Y. L. Liu, F. Pena-Mora, F. Boukamp, I. Odeh, M. Elseifi, and M. Hassan. 2007. *Nighttime Construction: Evaluation of Lighting Glare for Highway Construction in Illinois.* Illinois Center for Transportation.

Ellis, R. D., Z. J. Herbsman, A. Kumar, and P. N. Chheda. 1991. *Developing Night Operations in Florida.* Florida Department of Transportation. December 1991.

Ellis, R. D., and A. Kumar. 1993. Influence of Nighttime Operations on Construction Cost and Productivity. *Transportation Research Record.* Washington, DC: Transportation Research Board. pp. 31-37

Ellis, R. D., Z. J. Herbsman, P. N. Chheda, W. C. Epstein, and A. Kumar. 1993. *Developing Procedures for Night Operations of Transportation Construction Projects.* Transportation Research Center. University of Florida. Gainesville, Florida. January 1993.

Ellis, R. D. 2001. Lighting Fundamentals for Nighttime Construction. *Construction and Materials Issues 2001.* Proceedings of the ASCE Civil Engineering Conference. Houston, Texas. American Society of Civil Engineers.

Ellis, Ralph D., Jr., Scott Amos, and Ashisk Kumar. 2003. *NCHRP Report 498: Illumination Guidelines for Nighttime Highway Work.* Transportation Research Board of the National Academies, Washington, D.C. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_498.pdf.

Elrahman, O. A., and R. J. Perry. 1994. *Night-Time Construction Operations.* Special Report 116. Engineering Research and Development Bureau. New York State Department of Transportation. Albany, New York. 32 pp.

Elrahman, O. A. 2008. *Night-Time Road Construction Operations Synthesis of Practice.* Transportation Research and Development Bureau. New York State Department of Transportation. May 2008.

Farnham, J., and E. Beimborn. 1991. Techniques for Aesthetic Design of Freeway Noise Barriers. *Transportation Research Record 1312.* TRB, National Research Council, Washington, D.C., pp. 119–129.

Federal Highway Administration (FHWA). 2001. *Fact Sheet 1—Oregon's Quickfax Service,* http://www.ops.fhwa.dot.gov/wz/practices/factsheets/factsheet1.htm.

———. 2005a. *Work Zone Public Information and Outreach Strategies.* U.S. Department of Transportation. Federal Highway Administration. November 2005. http://ops.fhwa.dot.gov/wz/info_and_outreach/index.htm

———. 2005b. *Managing Demand through Travel Information Services.* U.S. Department of Transportation. Federal Highway Administration. http://ops.fhwa.dot.gov/publications/manag_demand_tis/travelinfo.htm

———. 2006a. *FHWA Highway Construction Noise Handbook.* U.S. Department of Transportation. Federal Highway Administration. Office of Natural and Human Environment, Washington, DC. August 2006. http://www.fhwa.dot.gov/environment/noise/handbook/index.htm.

———. 2006b. *Roadway Construction Noise Model Version 1.0.* U.S. Department of Transportation. Federal Highway Administration. February 15, 2006. http://www.fhwa.dot.gov/environment/noise/construction_noise/rcnm/rcnm.cfm.

———. 2009. *Manual on Uniform Traffic Control Devices for Streets and Highways.* 2009 Edition. U.S. Department of Transportation. Federal Highway Administration. Washington, DC. December 2009. http://mutcd.fhwa.dot.gov/pdfs/2009/mutcd2009edition.pdf.

———. 2011. *Project-Level Public Information and Outreach Examples.* U.S. Department of Transportation. Federal Highway Administration. http://www.ops.fhwa.dot.gov/wz/publicinfostrategies/project level.htm.

Figueiro, M. G., R. Kartha, B. Plitnick, and M. S. Rea. 2009. *Light Isn't Just for Vision Anymore: Implications for Transportation Safety.* Lighting Research Center. Rensselaer Polytechnic Institute.

Florida Department of Transportation (FDOT). 2010. *Standard Specifications for Road and Bridge Construction.* http://www.dot.state.fl.us/SpecificationsOffice/Implemented/SpecBooks/2010Bk.shtm.

Folkard, S., P. Totterdell, D. Minors, and J. Waterhouse. 1993. Dissecting Circadian Performance Rhythms: Implications for Shiftwork. *Ergonomics.* 36(1-3):282–288.

Freyssinier, J. P., J. D. Bullough, and M. S. Rea. 2008. Performance Evaluation of Semi-permanent High-Mast Lighting for Highway Construction Projects. *Transportation Research Record: Journal of the Transportation Research Board, No. 2055.* Transportation Research Board of the National Academies, Washington, D.C., pp. 53–59.

Gambatese, J. A. 2005. *Optimum Illumination for Nighttime Flagger Operations.* Oregon Department of Transportation. Federal Highway Administration.

Goel, N., H. P. A. Van Dongen, and D. F. Dinges. 2011. Circadian Rhythms in Sleepiness, Alertness, and Performance. 5th Edition. Chapter 38. M. H. Kryger, T. Roth, and W. C. Dement (eds.). *Principles and Practice of Sleep Medicine.* Elsevier.

Graham, J. L., R. J. Paulsen, and J. C. Glennon. 1978. Accident Analyses of Highway Construction Zones. *Transportation Research Record 693.* TRB, National Research Council, Washington, D.C., pp. 25–32.

Hancher, D. E. and T. R. B. Taylor. 2000. Night-Time Construction Issues. Study Number KYSPR 00-217. Kentucky Transportation Center. University of Kentucky. August 2000. 128 pp.

———. 2001. Nighttime Construction Issues. *Transportation Research Record, Journal of the Transportation Research Board, No. 1761.* TRB, National Research Council, Washington, D.C., pp. 107–115.

Hanna, A. S., C. S. Taylor, and K. T. Sullivan. 2005. Impact of Extended Overtime on Construction Labor Productivity. *Journal of Construction Engineering and Management.* American Society of Civil Engineers. 131(6):734–739.

Hanson, Carl E., David A. Towers, and Lance D. Meister. *Transit Noise and Vibration Impact Assessment.* 2006. FTA-VA-90-1003-06, US Department of Transportation. Federal Transit Administration. Washington, DC. May 2006. www.fta.dot.gov/documents/FTA_Noise_and_Vibration_Manual.pdf

Hinze, J. W., and D. Carlisle. 1990a. *An Evaluation of the Important Variables in Nighttime Construction.* Transportation Northwest (TransNow). University of Washington, Seattle, Washington. February 1990. 87 pp.

———. 1990b. Variables Affected by Nighttime Construction Projects. *Transportation Research Record 1282.* TRB, National Research Council, Washington, D.C., pp. 95–103.

Holguin-Veras, J., R. Baker, A. Medina, and D. Sackey. 2001. *An Analysis of Human Factors in Nighttime Work Zones.* New Jersey Department of Transportation. US Department of Transportation. Federal Highway Administration. November 2001. 65 pp. http://www.utrc2.org/research/assets/2/analysisnight1.pdf.

Horne, J. A., C. G. Brass, and A. N. Pettitt. 1980. Circadian Performance Differences between Morning and Evening "Types." *Ergonomics.* 23(1):29-36. January 1980.

Hyari, K., and K. El-Rayes. 2006a. Field Experiments to Evaluate Lighting Performance in Nighttime Highway Construction. *Construction Management and Economics.* 26(6):591-601.

———. 2006b. Lighting Requirements for Nighttime Highway Construction. *Journal of Construction Engineering and Management.* American Society of Civil Engineers. 132(5):435-445.

Illinois Department of Transportation (IDOT). 2002. *Standard Specifications for Road and Bridge Construction Adopted January 1, 2002.* http://dot.state.il.us/desenv/spec2007/div700.pdf.

———. 2008. Bureau of Design and Environment (BDE) Special Provision 80208 "Nighttime Work Zone Lighting." (Effective 11/1/08). No longer accessible online.

———. 2010. *Bureau of Design and Environment Manual – 2010 Edition.* www.dot.state.il.us/desenv/bdemanual.html.

Indiana Department of Transportation (INDOT). 2010. *2010 Standard Specifications.* http://www.in.gov/dot/div/contracts/standards/book/sep09/sep.htm.

Jiang, Y., and H. Wu. 2004. *Determination of INDOT Highway Construction Production Rates and Estimation of Contract Times.* Paper 331. Joint Transportation Research Program. Purdue University. West Lafayette, Indiana. 86 pp. http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1803&context=jtrp&sei-redir=1#search="Determination+of+INDOT+Highway+Construction+Production+Rates+and+Estimation+of+Contract+Times".

Kumar, A., and R. D. Ellis, Jr. 1994. Cost Variations in Nighttime Construction. *Transactions of AACE International.* TR1.1-TR1.8. Association for the Advancement of Cost Engineering.

Lee, C. D. 1969. Night-Time Construction Work on Urban Freeways. *Traffic Engineering.* 39(3):26–29.

Lee, C., M. R. Smith, and C. I. Eastman. 2006. A Compromise Phase Position for Permanent Night Shift Workers: Circadian Phase after Two Night Shifts with Scheduled Sleep and Light/Dark Exposure. *Chronobiology International.* 23(4):859–875.

Lee, E. B., and D. K. Thomas. 2007. State-of-Practice Technologies on Accelerated Urban Highway Rehabilitation: I-15 California Experience. *Journal of Construction Engineering and Management.* American Society of Civil Engineers. 133(2):105-113.

Lee, E. B., H. Lee, and C. W. Ibbs. 2007. Productivity Aspects of Urban Freeway Rehabilitation with Accelerated Construction. *Journal of Construction Engineering and Management.* American Society of Civil Engineers. 133(10):798–806.

Li, Z. 2010. Highway Work Zone Safety Audits for Safety Improvements. *Engineering, Construction and Architectural Management.* 17(5):512–526.

Lin, H., L. J. Pignataro, and Y. He. 1997. *Analysis of Truck Accident Reports in Work Zones in New Jersey.* The National Center for Transportation and Industrial Productivity Institute for Transportation. New Jersey Institute of Technology. August 1997. http://transportation.njit.edu/nctip/final_report/truckaccidART.htm.

Liska, R. W., Goodloe, D., and Sen, R. 1993. *Zero Accident Techniques.* Construction Industry Institute (CII). Austin, Texas.

Lisle, F. N. 1978. Evaluation of Timber Barricades and Precast Concrete Traffic Barriers for Use in Highway Construction Areas. *Transportation Research Record 693.* TRB, National Research Council, Washington, D.C., pp. 18–25.

Mattila, K. G., and M. Dina. 2003. Road construction production rates. In *Proceedings of the 2003 Associated Schools of Construction Great Lakes Region Annual Meeting.* November 6-8, 2003. Downers Grove, Illinois.

McCallum, M., T. Sanquist, M. Mitler, and G. Krueger. 2003. *Commercial Transportation Operator Fatigue Management Reference.* U.S. Department of Transportation, July, http://www.fra.dot.gov/downloads/research/fatigue_management.pdf.

McCallum, M. C., T. Sanquist, J. L. Campbell, and E. Jac. 2010. *Identifying and Reducing Worker, Inspector, and Manager Fatigue in Rapid Renewal Environments.* Task 3 Prepare Fatigue Assessment Plan. SHRP 2 R03. June 2010. Washington, DC: Transportation Research Board.

Minnesota Department of Transportation (Mn/DOT). 1997. *A Step in the Light Direction: The Mn/DOT Initiative to Enhance Personal Safety in Work Zones.* Videotape. St. Paul, Minnesota.

Miro, E., M. C. Cano, L. Espinosa-Fernandez, and G. Buela-Casal. 2003. Time Estimation During Prolonged Sleep Deprivation and Its Relation to Activation Measures. *Human Factors.* 45(1):148–159.

Molenaar, K., S. Anderson, and C. Schexnayder. 2010. NCHRP Report 658: *Guidebook on Risk Analysis Tools and Management Practices to Control Transportation Project Costs.*. Transportation Research Board of the National Academies, Washington, D.C., 119 pp. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_658.pdf.

Moore-Ede, M., S. Campbell, and T. Baker. 1989. Effect of Reduced Operator Alertness on the Night Shift on Process Control Operator Performance. *Advanced Instrumentation Control.* International Society of Automation (ISA) 89 International Conference Exhibition.

Nassar, K. 2008. Integrating Discrete Event and Lighting Simulation for Analyzing Construction Work Zone Lighting Plans. *Journal of Automation in Construction.* 17:561–572.

New, B. M. 1990. Ground Vibration Caused by Construction Work. *Tunneling and Underground Space Technology* 5(3). Great Britain.

New Jersey Department of Transportation (NJDOT). 2007. *New Jersey Department of Transportation Traffic Mitigation Guidelines.* www.state.nj.us/transportation/eng/documents/TMG/TMG.shtm.

New Jersey Department of Transportation (NJDOT). 2007a. *2007 Standard Specification.* http://www.state.nj.us/transportation/eng/specs/.

———. 2007b. *New Jersey Department of Transportation Traffic Mitigation Guidelines.* www.state.nj.us/transportation/eng/documents/TMG/TMG.shtm.

New York City Department of Environmental Protection (NYCDEP). 2007. *Notice of Adoption of Rules for Citywide Construction Noise Mitigation.* Title 15 Rules of the City of New York. Citywide Construction Noise Mitigation. Chapter 28. http://www.nyc.gov/html/dep/pdf/noise_constr_rule.pdf.

New York State Comptroller. 1999. *Department of Transportation Nighttime Construction Program.* Report 98-S-50. Division of Management Audit and State Financial Services. April 26, 1999. Albany, New York.

New York State Department of Transportation (NYSDOT). 1991. *Engineering Instruction—Night-Time Construction Policy.* February 19, 1991. 5 pp. https://www.nysdot.gov/portal/pls/portal/mexis_app.pa_ei_eb_admin_app.show_pdf?id=1218.

———. 2008. *2008 Standard Specifications (US Customary).* https://www.nysdot.gov/main/business-center/engineering/specifications/2008-standard-specs-us.

Noor, I. 1998. Measuring Construction Labor Productivity by Daily Visits. 42nd Annual Meeting of AACE. Association for the Advancement of Cost Engineering International. PR 16.

Office of the Federal Register. 29 CFR 1926.28. *Code of Federal Regulations.* US Government Printing Office. Washington, DC.

Oriard, L. L. 1989. The Scale of Effects on Evaluating Vibration Damage Potential. *15th Conference on Explosives and Blasting Technique.* Society of Explosive Engineers. Cleveland, Ohio.

Oregon Department of Transportation (ODOT). 2001. *Fact Sheet 1—Oregon's Quickfax Service,* http://www.ops.fhwa.dot.gov/wz/practices/factsheets/factsheet1.htm.

———. 2009. *Traffic Control Plans Design Manual.* Traffic-Roadway Section. Chapter 2 - Temporary Traffic Control Devices.

Park, S., K. D. Douglas, A. S. Griffith, and K. J. Haas. 2002. Factors of Importance for Determining Day-Time versus Night-Time Operations in Oregon. *Transportation Research Record: Journal of the Transportation Research Board, No. 1813.* Transportation Research Board of the National Academies, Washington, D.C., pp. 305–313.

Pennsylvania Department of Transportation (PennDOT). 2010. US202-700 Parkway Website. www.us202-700.com/pdf/Nighttime%20Construction%20202%2063_10.22.2010.pdf.

Price, D. A. 1985. *Nighttime Paving.* Final Report. CDOH-DTP-R-85-2, Federal Highway Administration and Colorado Department of Highways, Denver, Colorado.

———. 1986a. *Nighttime Paving.* In cooperation with the Federal Highway Administration. PB87-164257. Colorado Department of Highways. Denver, Colorado.

———. 1986b. *Nighttime Paving.* Implementation Report. CDOH/DTP/R-86/6. In cooperation with the Federal Highway Administration. Colorado Department of Highways. Denver, Colorado. April 1986.

Reagan, J. A. and Grant, C. A. 1977. *Highway Construction Noise Measurement Prediction and Mitigation.* U.S. Department of Transportation. Federal Highway Administration.

Rebholz, F. E., A. Al-Kaisy, K. Nassar, L. Y. Liu, K. El-Rayes, and L. Soibelman. 2004. *Nighttime Construction: Evaluation of Construction Operations.* Illinois Transportation Research Center. Illinois Department of Transportation. Edwardsville, Illinois. May 2004. 212 pp.

Rosekind, M., K. B. Gregory, and M. M. Mallis. 2006. Alertness Management in Aviation Operations: Enhancing Performance and Sleep. *Aviation, Space, and Environmental Medicine.* 77(12):1256-1266.

Sant, B. 2001. Solving the Work Zone Puzzle. *Occupational Health & Safety.* 70(6):46-50.

Schexnayder, C. J. 1999. Dealing with Nighttime Construction Nuisances. *Practice Periodical on Structural Design and Construction.* American Society of Civil Engineers. 4(2):77-82.

Schexnayder, C. J., and J. Ernzen. 1999. *NCHRP Synthesis 218: Mitigation of Nighttime Construction Noise, Vibrations, and Other Nuisances.*. TRB, National Research Council, Washington, D.C.

Shepard, F. D., and B. H. Cottrell, Jr. 1986. Benefits and Safety Impact of Night Work-Zone Activities. *Transportation Research Record 1086.* TRB, National Research Council, Washington, D.C., pp. 31–36.

Smith, R. J. 1995. Risk Identification and Allocation: Saving Money by Improving Contracting and Contracting Practices. *The International Construction Law Review.* 12:40–71.

Thalheimer, E. 2000. Construction Noise Control Program and Mitigation Strategy at the Central Artery/Tunnel Project. *Journal of Noise Control Engineering.* 48(5):157–165.

Thalheimer, E., and C. Shamoon. 2007. New York City's New and Improved Construction Noise Regulation. *Noise-Con 2007 Conference Proceedings.* Reno, Nevada. Institute of Noise Control Engineering. October 2007.

Thomas, H. R., C. T. Matthews, and J. G. Ward. 1986. Learning Curve Models of Construction Productivity. *Journal of Construction Engineering and Management.* American Society of Civil Engineers. 112(2):245–258.

Thomas, H. R., and I. Yiakoumis. 1987. Factor Model of Construction Productivity. *Journal of Construction Engineering and Management.* American Society of Civil Engineers. 113(4):623–639.

Thomas, H. R., W. F. Maloney, R. M. W. Horner, G. R. Smith, V. K. Handa, and S. R. Sanders. 1990. Modeling Construction Labor Productivity. *Journal of Construction Engineering and Management.* American Society of Civil Engineers. 116(4):705–726.

Toole, T. M. 2002. Construction Site Safety Roles. *Journal of Construction Engineering and Management.* American Society of Civil Engineers. 128(3):203–210.

Ullman, G. L., and R. A. Krammes. 1991. *Analysis of Accidents at Long-Term Construction Projects in Texas.* Texas Transportation Institute. College Station, Texas. June 1991. 103 pp. http://tti.tamu.edu/documents/1108-2.pdf.

Ullman, Gerald L., Melisa D. Finley, and Brooke R. Ullman. 2004. *Assessing the Safety Impacts of Active Night Work.* Texas Transportation Institute. College Station, Texas. http://tti.tamu.edu/documents/0-4747-1.pdf.

Ullman, G. L, B. R. Ullman, and M. D. Finley. 2006. Analysis of Crashes at Active Night Work Zones in Texas. *Transportation Research Board 85th Annual Meeting Compendium of Papers.* Paper #06-2384. Washington, DC: Transportation Research Board. CD-ROM.

Van Dongen, H. P. A., G. Maislin, J. M. Mullington, and D. F. Dinges. 2003. The Cumulative Cost of Additional Wakefulness: Dose-Response Effects on Neurobehavioral Functions and Sleep Physiology from Chronic Sleep Restriction and Total Sleep Deprivation. *SLEEP.* 26(2):117-126.

Washington State Department of Transportation (WSDOT). 2005. *Project Communication Plan.* www.wsdot.wa.gov/projects/projectmgmt/online_guide/phase_guides/Pre-Construction/PC_Plan_the_Work/PC_Plan_Communication.htm.

Woods, R. D. 1997. *NCHRP Synthesis 253: Dynamic Effects of Pile Installations on Adjacent Structures.*. TRB, National Research Council, Washington, D.C.

Wunderlich, K. and D. Hardesty. 2003. *A Snapshot of Summer 2001 Work Zone Activity: Based on Information Reported on State Road Closure and Construction Websites.* U.S. Department of Transportation. Federal Highway Administration. February 2003. http://ops.fhwa.dot.gov/wz/docs/2001wz_snapshot.pdf.

Acronyms and Abbreviations

AACE	Association for the Advancement of Cost Engineering
ANSI	American National Standards Institute
AWIS	Automated Work Zone Information Systems
CA4PRS	Construction Analysis for Pavement Rehabilitation Strategies
Caltrans	California Department of Transportation
CA/T	Central Artery/Tunnel
CII	Construction Industry Institute
CPF	Composite Pay Factor
dB	decibel
dBA	A-weighted decibel
DelDOT	Delaware Department of Transportation
DMS	Dynamic Message Signs
DOT	Department of Transportation
FCC	Federal Communications Commission
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
HAR	Highway Advisory Radio
HMI	Hydrargyrum medium-arc iodide
IESNA	International Engineering Society of North America
IEST	Institute of Environmental Sciences and Technology
IDOT	Illinois Department of Transportation
INDOT	Indiana Department of Transportation
IRI	International Roughness Index
ISEA	International Safety Equipment Association
ITS	Intelligent Transportation Systems
KVA	Kilovolt Amperes
KYTC	Kentucky Transportation Cabinet
Leq	Equivalent Sound Level
Lmax	Maximum Sound Level
Lmin	Minimum Sound Level
Ln	Percentile Sound Level
Lv	Vibration Velocity Decibel Level
MDOT	Michigan Department of Transportation
Mn/DOT	Minnesota Department of Transportation
MUTCD	Manual on Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
NJDOT	New Jersey Department of Transportation

NRC	Noise Reduction Coefficient
NYCDEP	New York City Department of Environmental Protection
NYSDOT	New York State Department of Transportation
OCI	Overall Condition Index
ODOT	Oregon Department of Transportation
OSHA	Occupational Safety and Health Administration
PennDOT	Pennsylvania Department of Transportation
PMBOK	Project Management Body of Knowledge
PPE	Personal Protective Equipment
PPV	Peak Particle Velocity
RMS	Root-Mean-Square
SAE	Society of Automotive Engineering
SRMP	Short Run Marginal Productivity
STA	State Transportation Agency
STC	Sound Transmission Class
TCP	Traffic Control Plan
TxDOT	Texas Department of Transportation
VdB	Vibration Velocity Decibel Level
VC	Vibration Criteria
WSDOT	Washington State Department of Transportation

APPENDIX

Sample Safety Quiz

This appendix contains a sample toolbox talk, written quiz, and answer sheet on safety activity responsibilities from the Washington State Department of Labor & Industries, which is also available at http://www.lni.wa.gov/safety/topics/atoz/toolboxtalks/PDFs/WhoseResponsibility.pdf.

This toolbox talk and others are also available at http://www.lni.wa.gov/Safety/Topics/AtoZ/ToolBoxTalks/default.asp.

Page 6

Whose Responsibility Is It?

After an accident has occurred, it is not unusual for those who were around the injured worker to feel guilty. This guilt is part of each person's inner awareness that there was possibly something they could or should have done to prevent the accident. Sometimes the accident is the result of someone else's mistakes. But who causes the accident is not as important as who is responsible for the accident, and what steps will be taken to correct future similar accidents from happening. The following is a partial list of responsibilities for safety on the job.

Guide for Discussion

Who's Responsible? (Discussion Points)

Senior company management?
Crew supervisor?
Each person on the job?
Trained safety professionals?
Company safety committee?

Some Responsibility Rules for Everyone

If it's unsafe for you then it's unsafe for the next person and the hazard should be corrected.

Safety doesn't belong to any one construction craft; rather it is part of every construction craft to be responsible.

If safety doesn't begin with you, it won't begin at all.

An Individual's Responsibility

To yourself
To your family
To your co-workers
To your company

Additional Discussion Notes: (See Pages 6A and 6B)

Remember: Workers' compensation checks won't pay all the bills nor will they replace the self-esteem one has from being a good provider to their families. Without complete cooperation from everyone on the worksite, it just will not be as safe as it should be.

Attendee's:

NOTE: Always promote a discussion on any of the topics covered in the Tool Box Talks. Should any question arise that you cannot answer, don't hesitate to contact your Employer.

Page 6A

Supplemental Information For
Whose Responsibility Is It
A Tool Box Talk

Instructor Note: This written test can be given to employees, supervisors, the employer and the company safety committee to reinforce training in "Whose Responsibility Is It." An answer sheet and a discussion topic is found on page 6B.

In our company, who is primarily responsible for the following safety activities?

E = Employee
SC = Safety Committee
S = Supervisor
EMP = Employer

__________ Complying with Safety Rules
__________ Conducting Safety Training
__________ Recognizing Others for Safety Performances (Good or Bad)
__________ Reporting Injuries or Illnesses
__________ Providing Feedback About Safe Work Procedures
__________ Enforcing Safety Rules
__________ Conducting Area Safety Inspections
__________ Selecting Personal Protective Equipment (PPE)
__________ Assessing Workplace Hazards
__________ Reporting Hazards
__________ Conducting Accident Investigations
__________ Rewarding Incentives
__________ Recommending Corrective Actions to Eliminate Hazards
__________ Demonstrating Safe Work Practices
__________ Training Safe Work Procedures to New Employees
__________ Ensuring Safe and Healthful Work Areas
__________ Monitoring Safety and Health Programs
__________ Showing Others How to Use Personal Protective Equipment
__________ Reporting Incidents or Near Misses
__________ Eliminating or Reducing Hazards
__________ Developing Safe Work Procedures
__________ Conducting Job Hazard Analyses

Supplemental Information For: Whose Responsibility Is It, Continued
Answer Sheet

Choices

E = Employee
SC = Safety Committee
S = Supervisor
EMP = Employer

Because each company is different, there are no single correct answers. However, one perspective of *primary* *responsibility recommends one of the following answers:*

E, SC, S, EMP	Complying with Safety Rules
SC, S, EMP	Conducting Safety Training
SC, S, EMP	Recognizing Others for Safety Performances (Good or Bad)
E, S	Reporting Injuries or Illnesses
E, SC	Providing Feedback About Safe Work Procedures
SC, S, EMP	Enforcing Safety Rules
SC, S, EMP	Conducting Area Safety Inspections
SC, EMP	Selecting Personal Protective Equipment (PPE)
SC, EMP	Assessing Workplace Hazards
SC	Reporting Hazards
SC, S, EMP	Conducting Accident Investigations
SC, EMP	Reward Incentives
E, SC, S	Recommending Corrective Actions to Eliminate Hazards
SC, S, EMP	Demonstrating Safe Work Practices
SC, S, EMP	Training Safe Work Procedures to New Employees
SC, S, EMP	Ensuring Safe and Healthful Work Areas
SC, S, EMP	Monitoring Safety and Health Programs
SC, S, EMP	Showing Others How to Use Personal Protective Equipment
E, S	Reporting Incidents or Near Misses
E, SC, S, EMP	Eliminating or Reducing Hazards
SC, S, EMP	Developing Safe Work Procedures
S, EMP	Conducting Job Hazard Analyses

Why such emphasis on Supervisors?

WAC 296-800-14020
The employer shall instruct each employee in the recognition and avoidance of unsafe conditions and the regulations applicable to his/her work environment to control or eliminate any hazards or other exposure to illness or injury.

Past WISHA rulings have indicated that:
"Any supervisor or persons in charge of work are held to be agents of the employer in the discharge of their authorized duties."

Authorized duties include:
(a) The execution in a safe manner of the work under their supervision;
(b) The safe conduct of their crew while under their supervision; and
(c) The safety of all workers under their supervision."

It makes good sense to hold supervisors responsible for the employees placed under their charge. It builds a sense of teamwork and shared responsibility for safe productivity. Supervisors are generally closer to the employees under their charge and better able to positively influence positive behavioral change.

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation