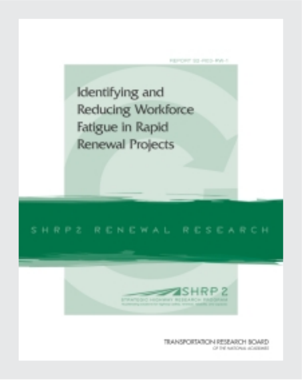

Identifying and Reducing Workforce Fatigue in Rapid Renewal Projects

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The Second
STRATEGIC HIGHWAY RESEARCH PROGRAM

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Identifying and Reducing Workforce Fatigue in Rapid Renewal Projects

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The Second Strategic Highway Research Program

America's highway system is critical to meeting the mobility and economic needs of local communities, regions, and the nation. Developments in research and technology—such as advanced materials, communications technology, new data collection technologies, and human factors science—offer a new opportunity to improve the safety and reliability of this important national resource. Breakthrough resolution of significant transportation problems, however, requires concentrated resources over a short time frame. Reflecting this need, the second Strategic Highway Research Program (SHRP 2) has an intense, large-scale focus, integrates multiple fields of research and technology, and is fundamentally different from the broad, mission-oriented, discipline-based research programs that have been the mainstay of the highway research industry for half a century.

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The research reported on herein was performed by Battelle, supported by EBL Consulting, Washington State University, The Minor Group, and Anderson Consulting. Thomas Sanquist, Battelle, was the Principal Investigator. The other authors of this report are Elizabeth Jackson, John L. Campbell, and Marvin McCallum, Battelle; E. B. Lee, EBL Consulting; and Hans Van Dongen and Peter McCauley, Washington State University. The authors acknowledge the contributions to this research from Glenna Redmond-Wolf, Jean Busto, and Diane Williams, Battelle; Melinda Jackson, Washington State University; Hollis Minor, The Minor Group; and Stuart Anderson, Anderson Consulting.

FOREWORD

Jerry A. DiMaggio, D.GE, PE, *SHRP 2 Senior Program Officer, Renewal*

This report, *Identifying and Reducing Workforce Fatigue in Rapid Renewal Projects,* describes a 3-year research project and results performed as SHRP 2 Project R03. The research scope involved studying factors associated with workforce fatigue and stress in the rapid renewal environment and the risks to worker safety and construction productivity. The study team developed an integrated fatigue management toolkit, including work scheduling and work practice guidance based on fatigue models, organizational practice guidance, fatigue management reference material, and training materials for managers and workers. This suite of products was prepared with the goal of integrating applicable components into existing safety management systems for highway projects, thereby reducing fatigue risk and increasing safety.

Worker and manager fatigue is a problem on highway construction projects and is exacerbated by the rapid renewal or accelerated construction practices that involve longer shifts, night work, and weekend closures. This problem is widely acknowledged by both management and labor, although current methods that address fatigue tend to be informal and are widely variable. Working conditions associated with rapid renewal approaches include conducting work during off-peak hours, continuous weekend construction, extended nighttime operations, and conducting work in zones adjacent to traffic. Fatigue countermeasures and their effectiveness have been studied extensively and are already practiced in other industries. Countermeasures include strategic management interventions (e.g., fatigue training, work scheduling aids, incident reporting) as well as individual interventions (e.g., sleep hygiene, napping, appropriate use of caffeine, self-monitoring and peer-monitoring).

A comprehensive description of factors contributing to workforce fatigue and stress in the rapid renewal environment was developed as part of this study. These factors were examined in a range of scenarios and in the ways in which different segments of the highway construction workforce are affected.

An integrated set of workforce fatigue risk factor definitions, fatigue risk management practices and techniques, and specific tools and procedures was developed into a toolkit that can be applied to comprehensively manage workforce fatigue. This toolkit complements the broader efforts of rapid renewal performance specifications, rapid renewal risk management, and rapid renewal project management. Training and outreach materials were also produced to support future workforce fatigue management efforts in the highway construction industry. Finally, an implementation strategy was prepared that identifies recommended activities to increase awareness of the potential risks and costs associated with workforce fatigue and stress, and to foster and reward industry members in adopting practices that manage these risks and costs.

CONTENTS

Executive Summary

Background

The National Highway System (NHS) is composed of 163,000 miles of significant rural and urban roads, including about 46,000 miles of the Interstate system. Many of the pavements on these highways, constructed during the infrastructure construction boom in the 1960s and 1970s, have exceeded their design lives due to continuously increasing traffic demand and aging without major renewal. This increased traffic comes at a time when many highway assets are reaching the end of their useful design life and need to be rebuilt or replaced.

To meet the challenge of aging and increasingly congested highways, rapid renewal construction approaches that minimize the impact of construction on traffic flow, especially during peak periods, are being developed and implemented. Working conditions associated with rapid renewal approaches include work conducted during off-peak hours, continuously through the weekend, during extended night-time hours, and in work zones adjacent to traffic. All of these working conditions have the potential to increase workforce fatigue and stress, resulting in reduced levels of workforce safety and construction productivity.

In response to these concerns, SHRP 2 Renewal Project R03, Identifying and Reducing Workforce Fatigue in Rapid Renewal Projects, was initiated so that the factors associated with workforce fatigue and stress in the rapid renewal environment can be understood and the risks to worker safety and construction productivity can be managed and reduced.

The project objectives are as follows:

- Document and assess the impact of human fatigue on work activities commonly associated with rapid renewal highway construction projects, including the impact on safety, quality, cost, and schedule.
- Develop strategies for organizing, structuring, and executing rapid renewal projects that incorporate fatigue reduction techniques into the project planning process.
- Evaluate a range of techniques that reduce fatigue and its effects on the workforce.
- Develop strategies for educating the rapid renewal highway construction community and its leaders on the importance of mitigating fatigue on rapid renewal projects.

To achieve these objectives, the team implemented a two-phase approach, involving initial research activities such as project and literature review and field work to document fatigue impacts, followed by a development phase that created contextually appropriate training, work schedule assessment, work practice guidance, and fatigue countermeasures. The team also addressed organizational issues and processes for implementation of fatigue risk management as an integral part of contractor safety management systems. A companion document, *SHRP 2*

Renewal Project R03: Guide to Identifying and Reducing Workforce Fatigue in Rapid Renewal Projects, contains specific implementation-oriented material for use by highway construction contractors, including superintendents and safety personnel. The guide includes organizational practices guidance, technical reference material such as fatigue countermeasures, training material, and work schedule risk assessment and guidance.

Fatigue in Operational Settings

An initial review of 13 selected rapid renewal projects in six different states suggests that rapid renewal practices include working during off-peak hours, continuously on weekends, at night, and in zones adjacent to traffic. While these strategies improve schedule performance, the associated conditions increase worker fatigue and stress and thereby reduce workforce safety and construction productivity. Shift workers are particularly prone to fatigue-related injuries if they work night shifts, extended shifts (10 or more hours), or weeks longer than 40 h.

Review of the scientific and technical literature shows that biological and environmental factors influence an individual's need for sleep. Fatigue is a function of both time awake (the homeostatic process) and time of day (the circadian process). Work-related fatigue is therefore a function of shift duration and shift timing: Long shifts may not provide adequate opportunity for rest; work at odd hours may require sleep during the day, resulting in poor sleep quality and less sleep obtained. Sleep deprivation affects both cognition and sensations of fatigue. Cognitive effects can include degraded alertness, difficulty concentrating, forgetfulness, and confusion, as well as impaired performance on specific tasks. Accumulated sleep deprivation can result in severe performance decrements. Individuals vary in their need for sleep and, therefore, in their responses to sleep loss. Sleep loss can be countered only by obtaining additional sleep; severe sleep loss can require substantial recovery time. Following sleep deprivation, subjective ratings of fatigue return to baseline more quickly than does cognitive performance.

Studies of the effects of restricted sleep in operational settings demonstrate that sleep loss degrades task performance, resulting in higher rates of medical errors, unsafe driving behaviors, and motor vehicle accidents. Fatigue has been implicated as well in aviation and rail accidents. Shift workers are particularly prone to fatigue-related injuries if they work night shifts, extended shifts (10 or more hours), or work weeks longer than 40 h. Construction workers have elevated risks for occupational injury and fatality compared with most other occupational groups. In construction, the likelihood of occupational injury is higher for those working extended shifts, night and evening shifts, and weekly overtime. A work culture that expects workers to be available for overtime work likely contributes to the relatively high risk of injuries and fatalities.

Field Study of Fatigue in Rapid Renewal Projects

To obtain a more detailed and practical understanding of the nature and severity of worker fatigue in rapid renewal highway construction, the team carried out a field study using survey and subject matter expert (SME) interview techniques. Recruiting for field research participants was based on the initial contacts to state Departments of Transportation (DOTs) provided by the TRB steering committee. From each of the six states solicited for involvement (New York, Florida, Washington, Utah, California, and Illinois), the team identified candidate projects as described in Appendix A, along with key state DOT contacts. These DOT contacts were further solicited for prospective participation as working group members and were requested to provide contacts with the contractor companies for those projects that were still in the active phase of construction. This was followed by an initial e-mail solicitation to the construction company project managers and followed up with telephone discussions with those companies expressing interest in supporting the research. The final set of projects for conducting field research and the time periods during which it was conducted are as follows:

- Florida, SR-50: March 2011
- New York, I-287: May 2011
- Washington, SR-520: February, March, June 2011

The team conducted interviews with 20 SMEs and administered the survey to 47 respondents, including both management and labor. Six SMEs were also surveyed, for a total of 61 unique respondents. SMEs were recruited primarily through snowball sampling, and survey respondents through convenience sampling. The SMEs were interviewed concerning common scheduling practices, observed fatigue issues, fatigue training, and countermeasures. Interview respondents came from a broad range of occupational types and included project managers, construction managers, project and field engineers, general superintendents, and inspection managers. Survey respondents represented a broad range of roles including engineers, inspectors, equipment operators, truck drivers, laborers, and traffic control workers. The survey instrument addressed a variety of schedule issues, sleep obtained under different schedules, attitudes towards fatigue, and use of countermeasures. Workers' exposure to fatigue and their experiences of fatigue were each assessed using several measures constructed from survey responses. The survey instrument and interview guide are provided in Appendix B.

A substantial amount of data were collected and analyzed, with key findings that include the following:

- General agreement that fatigue is a safety problem.
- Informal management heuristics for recognizing and limiting impacts of fatigue.
- Informal application of fatigue countermeasures such as caffeine use (96% of workers) and as-needed rest breaks.
- Occasional use of napping during down time or meal breaks (16% of workers).
- Management tendency to be "on call" during continuous work periods, resulting in severe sleep disruption.
- Among workers on conventional schedules, 36% reported either falling asleep on the job, being afraid they might, or having difficulty staying awake during their commute home. Among respondents working closure weekends, 67% reported similar sleepiness events.
- Closure work leads to a higher proportion of workers at risk for fatigue-related error (67%) compared with those working a conventional schedule (11%), based on prior sleep-wake modeling.
- With rapid renewal practices (e.g., weekend closures) workers reported excessive work hours. The nine respondents who worked the weekend closure reported an average of about 73 h of work by the end of the closure Saturday—that is, by the end of Day 6 of what for most of them was a 12-day stretch.

The project documented a general awareness of fatigue as a problem, especially for managers. However, across the job sites visited, the team found little evidence of focused, systematic attention to the problem. Investigators were assured that fatigue training did take place, but this training appears to have been largely informal, and may not have focused on the importance of sleep.

The key finding from the field research is that fatigue is a routine problem and that rapid renewal construction practices exacerbate it.

Fatigue Countermeasures

A separate task synthesized the research on fatigue countermeasures for potential application in the highway construction sector. Among the 18 fatigue countermeasures identified, the evaluation suggests that nine of them have potential near-term applicability in the rapid renewal environment, including the preventive countermeasures of adequate sleep, "defensive napping," a good sleeping environment, and limiting overtime or work schedule modification. Operational countermeasures include caffeine, napping, "anchor sleep," and rest breaks. Additionally, the short-term impact of exercise may be beneficial in getting people out of the work environment briefly, and self- or peer-monitoring is potentially effective in detecting fatigue-related error potential and correcting it. Fatigue education should be the basis for applying the countermeasures.

The key challenge in implementing fatigue countermeasures in the highway construction industry is the lack of an economic framework that would raise the issue to the level of a critical safety problem. Compounding this issue is the problem of a very wide range of organizations engaged in highway construction. They can range from relatively small companies to large joint ventures formed for the purpose of specific megaprojects. Since there is no standards-body oversight concerning working hours and safety in highway construction, fatigue risk management will need to be carried out by individual organizations, within the parameters established by a credible body. The main phases of implementation of fatigue risk management in the rapid renewal highway construction industry appear to be as follows:

- Raise awareness of risk factors and motivation to mitigate.
- Assess risk factors for specific project operations.
- Develop and implement fatigue training for workers and managers.
- Develop methods for monitoring and assessing risk factors and countermeasures.
- Identify fatigue-proofing strategies for specific operations.

Critical Issues for Fatigue Risk Management in the Highway Construction Industry

Evaluation of the field research data and the scientific-technical literature on fatigue in the context of established practices and operational constraints in the highway construction industry suggests a number of critical issues and risks associated with implementing fatigue risk management in this work environment. These include

- Fatigue is essentially a safety issue, yet one which is not "owned" by a specific stakeholder. The Occupational Safety and Health Administration (OSHA) establishes broad operating parameters for rest breaks and overtime pay, and more detailed safety oversight occurs at the state level. OSHA and state safety agencies simply require injury or accident reporting in a manner that allows documentation, but no root cause investigation that would allow fatigue to be implicated. The primary risk related to this issue is that the problem will continue to be acknowledged as a work-related risk, but one that does not warrant attention at a level sufficient to address it properly.
- Fatigue risk management programs are likely to be oversophisticated given the industry's current observed state of safety function implementation. Implementation of Fatigue Risk Management Systems (FRMS) implies a high degree of organizational development, including an existing safety management system, into which specific policies and practices concerning fatigue mitigation would be introduced. The principal risk related to this issue is that FRMS implementation guidance could be developed that would simply go beyond the capabilities of most contracting firms. Further, the team's field research suggests that fatigue and work scheduling currently play no role in risk assessment and contract award selection, and that attempting to introduce such approaches without a clear business value proposition would be problematic.
- Safety data about the effectiveness of interventions such as training and more sophisticated FRMS are extremely limited. Without demonstrated causal relationships between fatigue and accident/injury risk in the highway construction sector, and without solutions that have been shown to reduce the problem, operators are likely to conclude that they are doing the best they can and that they are operating in an acceptable risk space.

- A credible dissemination pathway for the suite of products is needed. Development of these products, such as fatigue training, countermeasure tools, guidance, and references, assumes the existence of a dissemination pathway to effectively distribute the material. The most important issue to be addressed concerns the mechanisms and responsibilities for an online repository, such as a regularly maintained website that can provide access to the various materials. Experience, however, has shown that a website is insufficient for widespread outreach. In addition, the website needs to be made broadly available through other organizations that are routinely contacted by highway construction safety personnel. Principal organizations would include the American Association of State and Highway Transportation Officials (AASHTO), the American Road and Transportation Builders Association (ARTBA), the Associated General Contractors of America (AGC), and possibly OSHA.
- An estimated 25,000 to 29,000 highway construction personnel will be engaged in rapid renewal work at some point over the next 10 years, and thus that is the estimated number of workers that could benefit from fatigue-oriented training.
- Subject to the limitations of available data, the team estimates that between 1,150 and 1,334 workers each year in the rapid renewal workforce would sustain an injury attributable to fatigue resulting from longer schedules.

Organizational Approach to Fatigue Risk Management in Rapid Renewal Highway Construction

An integrated approach to fatigue risk management for highway construction work needs to accommodate the unique characteristics of the environment, including the general industry approach to safety, the seasonal nature of construction work, and the likelihood of unpredictable schedule changes due to various factors such as weather, unforeseen obstacles, re-work, and so forth. This involves a series of organizational practices consisting of processes and implementation steps that will, over time, lead to a comprehensive approach to fatigue management.

Key elements of this approach are various educational materials, including basic worker and manager training modules for fatigue risk management. Additionally, specific work scheduling aids and work practice guidance based on biomathematical modeling are presented in this report and summarized in a separate guidance document. The basic product consists of specific shift schedule scenarios and variations, along with recommended fatigue countermeasures.

The most practical approach to work practice guidance for contracting firms is to use the findings from work schedule fatigue modeling to plan construction activities that incorporate knowledge of fatigue's impact on workers. Work practice guidance to address fatigue is a blend of specific tactics and countermeasure implementation, such as caffeine usage and worksite napping, and broader organizational practices associated with systematic evaluation and management of the problem. Unlike specific worksite problems such as traffic management or visibility, which can be addressed with procedures or technology such as lighting, work practices for fatigue management involve individual, crew, and organizational-level interventions.

Conclusions and Recommendations

The research findings have allowed the project team to develop a number of conclusions and recommendations about fatigue risk management in the highway construction industry. These include the following:

- Fatigue is clearly present in rapid renewal environments and presents considerable safety risks.
- Existing fatigue risk management programs cannot be used in rapid renewal environments; both development of a tailored suite of tools and implementation facilitation is required.

- The tools developed in this project have great potential for addressing the fatigue problems identified herein, but they must be introduced to relevant stakeholders and end users in a clear and supportive manner.
- Outreach would consist of a broad communications effort aimed at scientific and technical audiences as well as industry stakeholder groups.
- Outreach activities should be accompanied by an implementation effort to pilot test the materials developed in this product, evaluate their value and usefulness, and revise them to reflect stakeholder and end user feedback.

A realistic time frame for these activities is in the range of 12 to 18 months, in order to engage industry groups, conduct individual outreach meetings, and gather implementation-oriented feedback for potentially improving the product.

CHAPTER 1

Introduction and Background

The National Highway System (NHS) is composed of 163,000 miles of significant rural and urban roads, including about 46,000 miles of the Interstate system. Many of the pavements on these highways, constructed during the infrastructure construction boom in the 1960s and 1970s, have exceeded their design lives due to continuously increasing traffic demand and aging without major renewal. The FHWA recently released trend data indicating that the total number of vehicles over the last 40 years (1970 to 2010) has increased by 90% and the total freight movement (ton-miles) has increased by about 580%, while highway facilities (lane miles) have expanded by only 6%. This increased traffic comes at a time when many highway assets are reaching the end of their useful design life and need to be rebuilt or replaced.

In recent years state transportation agencies have shifted their focus from building new transportation facilities to "4-R" projects: restoration, resurfacing, rehabilitation, and reconstruction. Today, almost 61,000 miles (37%) of all lane miles on the NHS are in poor or fair condition. More than 152,000 bridges—one of every four bridges in the United States—are structurally deficient or functionally obsolete. The American Society of Civil Engineers (ASCE) has given low grades for the surface transportation system: Roads (D-), Bridges (C), Transit (D), and Rail (C). The ASCE estimated in 2005 that the nation's infrastructure would require an investment of $2.2 trillion over the next 5 years to bring the infrastructure to a state of good repair (Lee and Ibbs, 2005).

To meet the challenge of aging and increasingly congested highways, rapid renewal construction approaches are being developed and implemented to minimize the impact of construction on traffic flow, especially during peak periods. Working conditions associated with rapid renewal approaches include working during off-peak hours, continually on weekends, at night, and in zones adjacent to traffic. All of these working conditions have the potential to increase workforce fatigue and stress, resulting in reduced levels of workforce safety and construction productivity.

In response to these concerns, SHRP 2 Renewal Project R03, Identifying and Reducing Workforce Fatigue in Rapid Renewal Projects, was initiated so that the factors associated with workforce fatigue and stress in the rapid renewal environment could be understood and the risks to worker safety and construction productivity could be managed and reduced.

The results of Project R03 will support the overall SHRP 2 Renewal program objective of facilitating the development and implementation of effective rapid renewal construction approaches. By providing the highway construction community with tools and a strategy to address workforce fatigue and stress under the demanding conditions of rapid renewal projects, this project will help to ensure that rapid renewal projects are conducted safely and productively.

The project objectives are as follows:

- Document and assess the impact of human fatigue on work activities commonly associated with rapid renewal highway construction projects, including the impact on safety, quality, cost, and schedule.
- Develop strategies for organizing, structuring, and executing rapid renewal projects that incorporate fatigue reduction techniques into the project planning process.
- Evaluate a range of techniques that reduce fatigue and its effects on the workforce.
- Develop strategies for educating the community and its leaders on the importance of mitigating fatigue on rapid renewal projects.

To achieve these objectives, the team implemented a two-phase approach, involving initial research activities such as background information and literature review and field work to document fatigue impacts, followed by a development phase that created contextually appropriate training, work schedule assessment and work practice guidance, and fatigue countermeasures. The team also addresses organizational issues and processes for implementation of fatigue risk management as an integral part of contractor safety management systems.

This report consists of five additional chapters that integrate the results of the research and development phases of this project. Chapter 2 provides an overview of fatigue risk factors in rapid renewal work and illustrates them using 13 scenarios based on specific accelerated construction projects. This chapter also provides a detailed review of the scientific and technical literature on fatigue in operational work settings. Chapter 3 presents the results from field research conducted with three rapid renewal projects. Chapter 4 provides an overview of fatigue countermeasures and discusses prospective application in the highway construction environment. Chapter 5 outlines a number of critical issues related to implementing fatigue risk management for highway construction projects. Chapter 6 integrates the results of the project's development efforts by presenting (1) an organizational process and steps for implementing fatigue risk management, (2) training materials, (3) outreach approaches, and (4) work schedule and work practice guidance based on fatigue risk modeling.

The chapters of the report are supplemented by appendices with more detailed information on rapid renewal scenarios, field research survey instruments, and individual fatigue countermeasures. This report is complemented by a separate guide, *SHRP 2 Renewal Project R03, Guide for Identifying and Reducing Workforce Fatigue in Rapid Renewal Highway Projects,* that can be used by contractors and others for reference, training material, work schedule analysis, and work practice guidance.

CHAPTER 2

Fatigue in Occupational Settings

Fatigue Factors in Rapid Renewal Highway Construction

The initial research focus was to identify and describe representative rapid renewal construction scenarios that are expected to become more common in the future. The team reviewed current and past construction projects, solicited contacts within the state DOTs and construction communities, and reviewed current literature and DOT websites to help define these rapid renewal scenarios and illustrate each scenario with specific projects.

The team identified 13 examples of rapid renewal construction projects across six states (California, Florida, Illinois, New York, Utah, and Washington) and developed draft descriptions of these scenarios that included a project description, contract type and elements, work-shift schedules, specific workforce fatigue factors, and specific workforce fatigue countermeasures employed. These draft scenarios were distributed to state DOT staff, who were part of a Project Working Group established for this effort, with a request for them to review and, as necessary, revise the draft scenarios. Key aspects of the scenarios (especially the specific fatigue factors and fatigue countermeasures) were refined through field research. Appendix A provides the revised rapid renewal scenario descriptions.

This scenario task succeeded in identifying certain aspects of the work process that would be implicated in fatigue. These characteristics include the use of night work and weekend closures. Table 2.1 lists the specific work-shift schedules reported and areas for further research.

The information provided by the working group was not sufficiently detailed to determine how much night work or how many weekend closures were used. Subsequent experience in field work suggested that these elements of scheduling are fairly dynamic; use of any particular scheduling approach depends on the work to be done, the period in which it is required to be performed, weather factors, and so forth. For example, night work may be planned but not transpire because of delays in lane closure approval. For another example, a weather window anticipated to allow paving based on temperatures may be delayed due to low temperatures.

The impact of contract type on scheduling of the workforce did not appear to be significant in the projects reviewed and observed in the field. One contractor the team met with was working on two adjacent projects on SR-50 in Florida, with one of the projects being Design-Bid-Build and the other being Design-Build. In both cases, they used the same work scheduling and construction approaches. The more general observation with respect to work scheduling is the tendency of those projects that use continuous day–night construction to use two 10-h shifts, such as 7:00 a.m. to 5:00 p.m. and 8:00 p.m. to 6:00 a.m. This allows for more work to be completed following the set-up phase, and for activity to be curtailed during evening rush hour periods.

Scenario data also included information concerning workforce fatigue factors that respondents considered noteworthy. Table 2.2 lists these, with the team's interpretation of research issues and potential risk factors.

Table 2.1 and Table 2.2 summarize commonly occurring scenarios associated with rapid renewal highway work, although the extent of their usage in any particular project is unknown; determining it would require retrospective analysis of work schedule data, which was outside the scope of this task. While the schedule and fatigue factor descriptions provide some insight as to how the overall labor force is affected by rapid renewal scenarios, the impact on salaried workers is much less clear.

Fatigue countermeasures were reported for a subset of the projects catalogued for Task 1. These countermeasures are presented in Table 2.3.

The countermeasures described in Table 2.3 represent a range of approaches often employed in more comprehensive fatigue management programs, and include offsetting extended hours, stable assignments to specific shift times, limitations on extended work periods, and crew awareness and reporting. The

Table 2.1. Types of Work Schedules Described for Rapid Renewal Projects

Type of Schedule Reported	Area for Research
Normal day work	Assumed to mean 8-h shift
Night work	Shift length not specified
Weekend work	Shift pattern/length not specified
Extended day work	Assumed to mean more than 8 h, typically 10 h
Nonstop, multi-shift weekend work	Number of separate shifts and crews not specified
Extended weekend work—33 h	Number of separate shifts and crews not specified
7 day per week operations	Number of hours per day not specified
Double shifts	Assumed to mean same crew works 2 sequential 8-h shifts
2 or 3 shifts per day for one weekend	Assumed to be a closure
24-h-per-day operations with 3 shifts	Assumed to be 8-h shifts

Table 2.2. Workforce Fatigue Factors Reported for Rapid Renewal Projects

Workforce Fatigue Factors Reported	Research Issues and Risks
Shift schedules	Rotation or fixed assignment not specified; start or end times not specified.
Simultaneous operations in close proximity	High workload can enhance fatigue.
Deadline pressure to reopen lanes	Same as above.
High level of construction monitoring	Same as above.
Long-term night shifts	Potential for cumulative fatigue due to less sleep obtained by personnel on night shift.
Change shift to night work in middle of week	No time for adaptation to new start time; first few nights can be very difficult.
Overtime shifts follow 40-h week	Extended work week.

Table 2.3. Workforce Fatigue Countermeasures Used in Selected Projects

Countermeasure Reported	Implementation Considerations
Salaried workers offset extended workdays with shorter workdays following the long hours	Hourly workers not addressed by this approach
Outside workers were given water coolers, ice water, and water bottles	Addresses dehydration
Stability in shift assignment: day workers kept on days, night workers on nights	Reduces potential for disrupting established sleep schedules
Limitation of crew to one 10-h shift per 55-h weekend closure	Permits recovery day
Crew instructed to alert supervisors to issues related to long work hours	Crew awareness of fatigue effects incorporated into management policy

extent to which these measures are used is not clear, since they were voluntarily reported in an open-ended question about fatigue countermeasures. There does seem to be awareness of worker fatigue as a problem, especially in relation to extended work periods and night work, but the scope of this task did not permit a detailed assessment of the extent or formality of countermeasure usage.

Review of Scientific and Technical Research Literature

Introduction

There exists an extensive scientific literature exploring the relationship between fatigue and adverse outcomes in occupational and transportation settings. In occupational studies, aspects of work schedules are examined as preconditions for fatigue-related adverse outcomes such as error, injury, and death. In some cases, work performance is measured in the field, either as an indicator for fatigue or as a proxy for presumed risk of an accident or incident. Measurement of fatigue itself is problematic; it is not directly observable and must be inferred from other, measurable phenomena. Fatigue is the presumed mechanism linking long periods of wakefulness and performance-related adverse events (Williamson et al. 2011). Therefore, the effect of work schedule on safety and effective job performance is hypothesized to operate primarily through prior sleep–wake history and the time of day at which work takes place.

This literature review is intended to provide the foundation for a model of rapid renewal workforce fatigue and its management. First, this section will discuss the biological and environmental processes governing fatigue. Then, it reviews the effects of fatigue on job performance in operational settings. Next, this section examines evidence from selected occupational studies linking identified fatigue "precursors" with occupational injuries, followed by a review of findings from the limited set of studies of occupational injuries and deaths within the construction industry. Finally, it explores integrated models for fatigue management, including discrete countermeasures, some of which are appropriate for deployment on job sites.

Biological and Environmental Processes Governing Fatigue

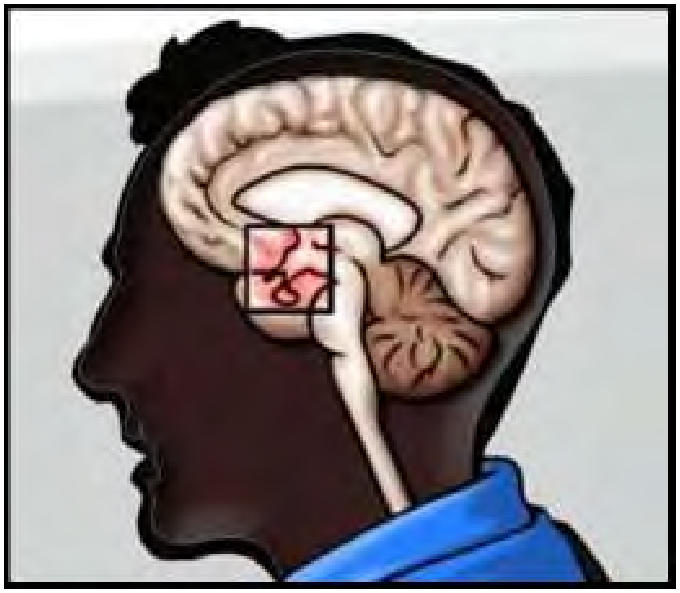
Biological Processes

There is a fundamental neurobiology underlying fatigue and how it affects neurobehavioral performance in the workplace. This neurobiology is tightly coupled with sleep regulation. The natural timing and duration of sleep is governed by two principal biological processes: a homeostatic process and a circadian process (Borbély 1982).

The homeostatic process seeks to balance the amounts of wakefulness and sleep, such that extended wakefulness results in a buildup of pressure for sleep. If this pressure for sleep is not met, sleep deprivation occurs and fatigue results (Daan, Beersma et al. 1984). As such, fatigue is regulated by the homeostatic process as a function of sleep/wake history. Getting sleep is a necessity to reduce fatigue resulting from the homeostatic process. Restricting sleep leaves a person with leftover sleep pressure, which, when repeated over several days, causes an accumulation of fatigue (Van Dongen et al. 2003). Cumulative fatigue from chronic sleep restriction results in sensitization to further sleep loss and a need for multiple recovery sleep periods (days to weeks) (Belenky et al. 2003).

The circadian process is a 24-h rhythm produced by the endogenous biological clock (located in the suprachiasmatic nucleus in the hypothalamus, shown in Figure 2.1). It promotes wakefulness during the day and sleepiness during the night, making staying awake through the night a challenge even if one manages to get enough sleep beforehand. Indeed, 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), thereby interfering with the homeostatic process by causing sleep restriction in people attempting to sleep during the day.

During daily awake hours, circadian rhythms lead to predictable changes in alertness, such as the tendency to feel sleepy at some point during the afternoon (often referred to as the



Source: McCallum et al. 2003.

Figure 2.1. Location of the brain's biological pacemaker that controls circadian rhythms.

"post-lunch dip," although the alertness drop has more to do with the point in the circadian cycle and less to do with whether you have eaten). Alertness in humans is typically lowest between midnight and 5:00 a.m., which corresponds to the period when melatonin levels are highest (Czeisler and Dijk 2001).

Sleep inertia refers to a transient reduction in neurobehavioral performance capability immediately upon awakening (Milner and Cote 2009). Sleep inertia may be observed following sleep periods of about 30 mins or more, especially in people who are sleep deprived or who are awakened early in the night (near the circadian nadir) and/or before the need for sleep is fulfilled (i.e., sleep is restricted) (Dinges 1990). Depending on the magnitude of sleep inertia, it may adversely affect neurobehavioral performance for up to about 2 h after awakening (Achermann et al. 1995), but most of the impairment dissipates within the first 15 min. A person experiencing sleep inertia may not be suitable to get back to work until some time for recuperation has passed (time that can be usefully spent taking a shower or eating breakfast). Caffeine counteracts sleep inertia (Van Dongen et al. 2001), and it has been suggested that taking caffeine prior to a nap might be a good strategy to avoid sleep inertia upon awakening (Reyner and Horne 1997).

Environmental Processes

The body's circadian rhythms can be disrupted by external cues that are inconsistent, out of phase with the established rhythm, or both. Such disruptions can affect an individual's ability to fall and stay asleep as well as the quality of the resulting sleep. External cues, particularly light–dark patterns, can reset the circadian pacemaker. This enables individuals to adjust to schedule or time changes. The length of time required for the adjustment depends on how extreme the changes are and on individual variability (Suvanto et al. 1987). Jet lag, for example, occurs when an individual's circadian rhythm is different from the day–night and activity patterns of the local environment. Most people can adjust their sleep–wake cycle to a full 12-h time zone change within a few days, although recent research indicates that disruption of sleep stages may persist past the time an adjusted sleep time has been established. It is more difficult for people to adapt to work schedules that are 12 h out of phase with their circadian rhythm than to accommodate a 12-h time-zone change. This is because the pattern of light and dark, some surrounding activities, and the sleep–wake schedule continue to be in conflict—unlike the case with a time-zone shift where light–dark schedules, activities, and sleep–wake schedules all shift together. The circadian pacemaker of individuals, such as shift workers, who switch temporarily from one activity–rest pattern to another, as on weekends, can become chronically disrupted and misaligned with external time (Monk 2000).

Process Interactions

The homeostatic process and the circadian process interact to determine the level of fatigue and neurobehavioral performance and the way in which they change over time (Van Dongen and Dinges 2005). As such, fatigue in the workplace is a function of both time awake (due to hours of service) and time of day (due to the work schedule) (Åkerstedt 2007) and thus of the nature of the work. Results from a study examining work scheduling in U.S. construction workers have shown that overtime and irregular work schedules adversely affect worker safety (Dong 2005). Second jobs, family obligations, recreational activities, and other social factors similarly co-determine fatigue through time awake and time of day.

A large body of empirical data shows that fatigue is reduced by sleeping longer or in a more consolidated manner (i.e., less frequently interrupted by brief awakenings) (Banks et al. 2010). In addition, prior sleep history (over days to weeks) determines vulnerability to fatigue (Belenky et al. 2003; Rupp et al. 2009). Inadequate sleep (excessive wakefulness) over successive sleep–wake cycles results in a "sleep debt" that has measurable neurophysiological consequences (Spiegel et al. 1999; Sallinen et al. 2004; Van Dongen et al. 2003). There is substantial individual variation in the sleep homeostatic process; that is, there are long sleepers and short sleepers (Aeschbach et al. 2001; Van Dongen et al. 2005).

Understanding the underlying neurobiology is critical to the issue of fatigue, because these homeostatic and circadian processes are active always in everyone. There are many other factors, both internal and external, that regulate fatigue, but by and large these other factors are determined by circumstance and their effects are primarily transient. However, the homeostatic and circadian regulation of fatigue is always present, comparatively powerful, and highly predictable (McCauley et al. 2009), making it both critical (Caruso et al. 2006; Ricci et al. 2007) as well as manageable (Smiley 1998; Dawson and McCulloch 2005) in operational settings.

Effects of Fatigue

Physiological effects of fatigue experienced by the person are different from performance effects. The physiological symptoms or manifestations of fatigue, such as blinking, facial tone, and posture, might be better thought of as indicators of the state of fatigue. Indicators of the state of fatigue can have limited value if the primary issue is whether the person presents a concern about degraded performance. Interpersonal variability in the extent to which indicators of the state of fatigue predict performance degradation (Oonk et al. 2008) might make it preferable to directly measure degraded performance. On the other hand, directly measuring performance degradation might not provide sufficiently early detection. Moreover, performance degradation can be caused by factors other than fatigue and, as such, is not by itself a very accurate indication that fatigue is an issue.

Cognitive indicators of fatigue can include degraded alertness and attention, problems with sustained concentration, tendency to be easily distracted, confusion, forgetfulness, memory problems, and performance worries. Psychomotor and cognitive speed, vigilant and executive attention, working memory, and higher cognitive abilities appear to be particularly affected by sleep loss (Lim and Dinges 2010). These cognitive decrements can accumulate to severe levels over periods of chronic sleep restriction without the full awareness of the affected individual (Van Dongen et al. 2003). Affect indicators can include demotivation (such as boredom, lack of desire and enthusiasm, or temporary feelings of depression) and coping, emotional, or interactional fatigue (such as anxiety, avoidance, comfort seeking, irritability, or feeling stressed) (Luna et al. 1997; Kamdar et al. 2004). These effects show considerable variability across individuals (Van Dongen et al. 2005). Microsleeps, sleep attacks, and lapses in cognition are considered to be an indication of state instability (i.e., short-duration transitions between sleep and wake states) (Doran et al. 2001). The following effects of fatigue are generally agreed upon in the scientific literature (Caldwell et al. 2008):

- Accuracy and timing degrade;
- Attentional resources are difficult to divide;
- A tendency toward perseveration develops;
- Social interactions decline;
- The ability to logically reason is impaired;
- Attention wanes;
- Attitude and mood deteriorate; and
- Involuntary lapses into sleep begin to occur.

Sleep and Recovery: A Selective Survey of Recent Studies

Sleep loss and disrupted sleep are the underlying causes of fatigue that are addressed by work-hour regulation and fatigue-management policies. Time on the job is clearly a factor, as shown by the risk profiles of time-into-shift by Folkard (1997), but it is increasingly recognized that sleep history and sleep that is obtained in the 24 h before the work period are critical elements of how rested and alert a worker will be (Dawson and McCulloch 2005). This section selectively reviews the state of knowledge regarding the impact of sleep on fatigue, alertness, and operational safety and recent work concerning sleep deprivation and recovery opportunities.

Sleep Need and Individual Differences

Work-hour regulations have at their basis the assumption that rest and recovery time (hence the amount of sleep workers obtain) depends on how much time people are at work. There is some basis for this assumption, as shown by a time-use survey of sleep in relation to waking activities (Basner et al. 2007). Analysis of extensive survey data obtained in the American Time Use Survey suggests that the only variable showing a reciprocal relationship with amount of time reported sleeping is the amount of time reported working. The correlation is not large (–0.36 for weekdays), but it is significant. More detailed analysis of the data indicates that average sleep time was lowest for the 45- to 54-year-old age group (7.8 h), and that sleep time decreases with increasing income.

The time-use survey data raise the proverbial question of how much sleep is really needed. This issue was discussed extensively by Ferrara and De Gennaro (2001) in a review that addressed historical surveys of sleep habits; sleep deprivation effects on sleep structure, performance and alertness; gradual and long-term sleep reduction; sleep extension; and individual differences and sleep typologies such as long and short sleepers. There has been a gradual curtailment of sleep with the increased pace and activity of modern society, from a modal number of nocturnal hours of 8 to 8.9 in 1959 to 7 to 7.9 in the mid-1980s. There are many methodological issues associated with epidemiological surveys of this sort, but the bulk of historical data support the conclusion that sleep time has decreased in the past 100 years.

In terms of how much sleep is enough, the theories and data are quite varied, with notions of "core sleep" of 4.5 to 6 h (Horne 1988) being sufficient countered by sleep extension studies suggesting that people can sleep as much as 9 h when no restrictions are applied. "Long night" studies, in which subjects remained in bed for 14 h each night for a 4-week period, showed that subjects slept an average of 10.6 h per night, compared with a control group that slept 7.6 h when given 8 h in bed. However, by the 4th week of the study, the average total sleep time was about 8 h, suggesting that a preexisting sleep debt had recovered in the first weeks, and that extra rest time available led to only an additional 30 to 60 min of sleep (Wehr et al. 1993). The general conclusion from this work is that sleep deprivation does affect performance and alertness, sleep extension appears to show no substantial benefits for average individuals, and large differences exist among individuals. This latest point is quite important in considering fatigue management programs in industry, because it is not possible to establish a specific amount of time to satisfy the physiological sleep need, although it is clear that the number of hours of prior wakefulness is positively correlated with subsequent sleep duration. That is, sleep duration depends on the amount of need for sleep (Åkerstedt 2007).

Individual Differences in Response to Fatigue

There are marked individual differences in the neurobehavioral response to fatigue. This is reflected in wide-ranging levels of performance impairment between subjects that are stable within subjects over time (Van Dongen et al. 2004). Thus, some individuals are highly vulnerable to performance impairment due to sleep loss, while others are relatively resilient. Workers may not be aware of their own vulnerability to neurobehavioral performance impairment due to fatigue; there is little congruency between subjective reports of sleepiness and objectively measured performance following sleep loss (Leproult et al. 2003; Van Dongen et al. 2004). Individual differences can originate in multiple factors implicated in the regulation of fatigue, including sleep need (Aeschbach et al. 1996), circadian timing (commonly recognized as the trait of morningness/eveningness; Kerkhof and Van Dongen 1996), tolerance to shift work (Van Dongen and Belenky 2009), and sensitivity to caffeine (Retey et al. 2006). In addition, sleep disorders and other medical conditions may contribute to between-subjects variability in the effects of fatigue, in complex ways (Oonk et al. 2008). Research suggests that when workers are allowed to select their own occupations and shift schedules, they tend to select those that are least challenging, a situation that which has been an issue in many studies of shift work tolerance (Härmä 1995). However, there is evidence that self-selection does not eliminate individual variability in vulnerability to fatigue (Van Dongen et al. 2006).

Sleep Patterns, Fatigue, and Performance

The findings reviewed indicate that sleep disruption and deprivation are associated with performance decrements. Most of the data come from laboratory settings where it is possible to control sleep time and to 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, that is, the longer a subject is sleep deprived, the greater the effect (Van Dongen et al. 2003). These effects are most pronounced for performance tests; subjective ratings show an initial increase in sleepiness that levels off after the 1st or 2nd day. The Van Dongen et al. (2003) results confirm and elaborate upon the basic notions of sleep debt and the cumulative impact of sleep deprivation proposed on the basis of early studies (Carskadon and Dement 1982).

The basis for some performance decrements is the amount of time spent on the task, and ultimately how the work time affects the opportunity for sleep. Time-on-task effects are observed as a performance decrement on a single task the longer one is engaged in the task (Bills 1937). Time-on-task effects are particularly evident in tasks requiring sustained attention (Basner et al. 2008). The effect appears to be exacerbated by monotony, particularly in tasks that are machine paced (Koslowsky and Babkoff 1992) so that compensatory slowing down is not an option. The homeostatic and circadian processes interact with time-on-task effects when the homeostatic drive for sleep is elevated, the circadian drive for wakefulness is reduced, or both (Van Dongen and Belenky 2008). Rest breaks, either with or without sleep, and task switching provide recuperation from the time-on-task effect (Van Dongen et al. 2010). Breaks are also useful to reduce the impact of fatigue on safety in that they temporarily remove a person from harm's way.

The relationship of laboratory findings to operational settings is suggestive but not complete. Philip and Åkerstedt (2006) review a substantial number of transport and industrial safety studies that point to disrupted sleep as an underlying factor in accidents. The principal finding from a number of on-the-road studies is that truckers and car drivers do not get enough sleep just before a long trip. Åkerstedt (2007) suggests that there is a need for addressing white-collar work in addition to transport and industrial settings. Evidence for the relationship of sleep deprivation to on-the-job safety in cognitive work comes from a study by Landrigan et al. (2004), which showed that reducing work hours for on-call physician interns reduced serious errors by 50%. This finding suggests that risky decision making is affected by sleep deprivation, a subject which was addressed by McKenna et al. (2007). This group evaluated performance on a choice task involving risk and how it was framed (potential gain or loss). The results suggest that sleep deprivation decreases risk taking when a potential loss is presented, but increases risk taking when the problem is framed as a potential gain. In terms of operational implications, these results suggest that framing decisions in terms of conservative approaches for those working shifts with sleep-deprivation potential may be a reasonable strategy.

A considerable amount of research concerning shift work has been performed over the years (Åkerstedt 1998), and continues to be elaborated on and refined. The basic complaint of disturbed sleep in shift workers was investigated in a large study by Åkerstedt et al. (2008) to determine the specific complaints underlying "shift-work sleep disorder." This study compared shift workers, day workers, and insomnia patients on responses to a 300-item health and work environment questionnaire, which included items from the Karolinska Sleep Questionnaire. The principal finding for shift workers was that they reported more frequent "too little sleep" and "nodding off at work." Insomniacs reported substantially more sleep problems, and the authors conclude that shift-work disorder complaints are a distinct category. Introducing a single nap in the midst of a night shift improves mood and quality of work evaluations without disrupting the main sleep episode during the day (Bonnefond et al. 2001).

Recovery from Sleep Deprivation

Early studies of sleep deprivation suggested that following a single sleepless night, it takes more than a single full sleep episode to recover. This conclusion was based primarily on the sleep latency test and EEG parameters indicating that physiological changes persisted beyond the first recovery day. The issue of recovery is central to work-hour and scheduling policies, so an understanding of the dynamics of rest periods in relation to alertness and performance is important (Belenky et al. 2003; McCauley et al. 2009; Banks et al. 2010). The main work in this area appears to consist of laboratory studies. Two recent examples provide illustrative findings.

Lamond et al. (2007) induced moderate (1 sleepless night) and severe (2 sleepless nights) sleep deprivation in subjects, followed by five recovery nights that were either augmented (9 h) or restricted (6 h). After moderate sleep deprivation, a single night of 9 h sleep was sufficient to return alertness and performance to baseline levels; the physiological measure of sleep latency returned to baseline after two recovery nights. However, if the recovery opportunity was restricted to 6 h—in effect inducing additional sleep deprivation—none of the measures returned to baseline levels. Severe sleep deprivation was evaluated only with 9-h recovery periods. In this condition, alertness recovered after a single 9-h sleep, physiological measures (sleep latency) recovered after two 9-h sleeps, but performance remained below baseline for the entire recovery period.

A similar study was reported by Axelsson et al. (2008), in which subjects were restricted to 4 h of sleep for 5 days, followed by 7 recovery days of 8-h duration. Sleepiness scores increased and performance scores deteriorated over the restricted sleep days. After 3 recovery days, sleepiness scores returned to baseline, but the performance scores did not. More detailed analysis of the data showed substantial individual differences in performance scores, but not in the sleepiness scores, suggesting that trait-like characteristics may lead to differential effects in performance across individuals that are not reflected in self ratings of sleepiness. The implication of this is that while two people may rate themselves as equally alert, one may perform substantially worse than the other.

A report by Åkerstedt et al. (2000), integrating findings from a number of laboratory and operational studies, suggests that following extended and/or irregular work hours, 2 days and possibly more are necessary for full recovery. This must be balanced by workers preferring backward rotating shifts in order to obtain additional time off; these shifts have the adverse effect of progressively reducing sleep duration during the days on which work is assigned (Signal and Gander 2007). Age tends to influence the preference for various shift and recovery schedules, with younger people preferring rapidly rotating systems that allow greater time off (Kecklund et al. 2008).

The data concerning sleep deprivation and recovery periods is particularly pertinent to the question of what constitutes an appropriate recovery period following work. Proposed rules for the nuclear industry, for example, mandate a 10-h period between successive shifts, which is comparable to other industries such as trucking (10 h) and aviation, which has a graded recovery period based on prior time spent flying. The key finding that bears on recovery period length is that when recovery sleep is limited, recovery of performance is insufficient. Limited recovery might be analogous to lengthened operational shifts with 8 or fewer hours off between them.

Fatigue and Job Performance in Operational Settings

Published studies of task-specific performance decrements related to fatigue occur primarily in the domains of medicine and surface transportation, and to a lesser extent in aviation, rail, and military settings.

Medicine

In medicine, most studies focus on the effects of very long, overnight shifts of 24 h or more, which are typical of physician training programs; such schedules have been demonstrated to result in sleep loss among medical interns (Lockley et al. 2004; Barger et al. 2005). Studies of medical staff in the field and in the lab have repeatedly shown an association between sleep loss and impaired job performance, including attentional lapses and medical errors. Studies uniformly conclude that the 24+ h shifts typical of residency programs should be eliminated.

A series of studies looked at medical error, injuries, and accidents for interns over various types of rotations (Barger et al. 2006; Barger et al. 2005; Ayas et al. 2006). These studies used case-crossover designs where subjects were their own controls, and the studies relied upon self-reporting to measure outcomes. In one study, they examined the risk of self-reported, fatigue-related medical error and associated adverse medical events during months when participating interns had no extended shifts (baseline), one to four extended shifts, and five or more extended shifts (Barger et al. 2006). An extended shift was defined as a period of at least 24 h continuously at work. Compared to baseline, odds ratios (ORs) for significant medical errors were 3.5 [95% confidence interval (CI) 3.3 to 3.7] and 7.5 (95% CI 7.2 to 7.8), respectively. Odds ratios for related adverse events were 8.7 (95% CI 3.4 to 22) and 7.0 (95% CI 4.3 to 11), respectively, compared to baseline.

A similar study used several methods, including a team of chart reviewers and physician observers, to record and rate errors made by interns during traditional (~80 h per week with regular extended shifts) versus intervention (no extended shifts) work schedules on an intensive care unit (Landrigan et al. 2004). Interns on the traditional schedule made 35.9% more errors overall, and 56.6% more non-intercepted errors than those on the intervention schedule. Rates of serious error (22% higher), medication error (20.8% higher), and diagnostic error (OR 5.6) were all higher among interns on the traditional schedule.

An experiment using within-subjects comparison of 12 medical residents examined the effect of sleep loss and shift duration on "high-fidelity" simulated patient care over a 24-h period (Sharpe et al. 2010). Researchers found that errors during performance of routine tasks remained low over the period, but that residents committed increasing errors during complex tasks as wakefulness increased. However, they also found that error rates and self-reported impact of wakefulness were not correlated.

A study of generalized performance in a medical setting followed anesthesia specialists and trainees for 2 weeks, recording sleep loss (diary and actigraphy), work shift and duration, and Psychomotor Vigilance Tests (PVTs) at the beginning and end of each shift (Gander et al. 2008). Among trainees, who regularly worked night shifts, PVT was degraded at night compared with daytime shifts, and declined as the night shift progressed; acute sleep loss was associated with degraded performance on night shifts. Among specialists, PVT worsened over the course of 12 consecutive days on duty, and declines were associated with acute sleep loss. In another study of medical residents, attentional lapses, as measured by continuous electro-oculography, occurred twice as frequently during night shifts as during days, and 1.5 times as frequently on day shifts for those on the traditional (not intervention) work schedule (Lockley et al. 2004).

Driving

The relationship among self-report measures, EEG, and driving performance was reported by Horne and Baulk (2004). In this study, participants were sleep restricted to 5 h the night before performing in a 2-h simulator drive. Sleepiness measures were obtained every 200 s, and lane crossings were counted as safety incidents. The results showed very strong correlations between EEG and sleepiness scale scores (0.93) and between sleepiness scores and incidents (0.88). Horne and Baulk believe that the results demonstrate that drivers are aware of physiological sleepiness as it occurs. The implication of these results for actual driving or other operations is that people need to be educated regarding the meaning of their subjective sense of fatigue so that they can make responsible decisions about rest versus continued activity. For example, in the driving situation, Horne and Baulk (2004) discuss the likely actions drivers would be taking when they reach the lane-deviation state of fatigue; that is, sleepiness scale 8 or 9, which embodies "fighting sleep." In this state, drivers tended to open the window and shift their postures in an attempt to stay awake. It is hoped that proper understanding of the meaning of this state by drivers would encourage them to take appropriate precautions by pulling off the road and resting.

A series of similar studies to that of Horne and Baulk (2004) has also shown the close link between self-ratings of sleepiness and the occurrence of fatigue or actual incidents. Smith et al. (2005) conducted a diary study of young drivers that showed their self-rated alertness was below critical levels during 2.6% of their driving episodes. Ingre et al. (2006) showed that sleepiness ratings were strongly related to absolute risk of an accident, based on simulator performance. For example, with a Karolinska Sleepiness Scale (KSS) score of 9 (fighting sleep) the average subject's risk increased by 185 times; however, differences among individuals in accident-likelihood complicate the use of prediction at the individual level.

Jones et al. (2006) studied sleep-deprived subjects in a performance and self-rating study with questions designed to assess their perceived ability to drive and the perceived ability of another who is similarly sleep deprived (a "hypothetical other"). Self-ratings declined substantially with increasing sleep deprivation and were correlated 0.7 to 0.76 with performance. Ratings for self-performance were somewhat higher than for the hypothetical other, suggesting that subjects had more confidence in themselves than someone else in the same condition. Dorrian et al. (2007) conducted a simulated train-driving study with actual locomotive drivers suggesting that as fatigue increases, certain error types increase as drivers become "disengaged" with the task.

Aviation

For more than 10 years, the National Transportation Safety Board (NTSB) has included fatigue on its "Most Wanted List" of advocacy priorities for aviation safety. In 2008 the NTSB recommended that the Federal Aviation Administration develop guidance, based on empirical studies and scientific research findings, to manage fatigue in aviation operations. This recommendation followed key fatigue-related mishaps, such as the crash of Corporate Airline flight 5966, the runway overrun by Delta connection flight 6488, the off-runway excursion of Pinnacle Airlines flight 4712, and the airport overshoot by go! flight 1002 (Caldwell 2009).

While these mishaps implicated fatigue as a contributor, systematic data on the number of fatigue-related aviation accidents do not exist. A recent NTSB analysis of aviation accidents based on the Aviation Accident Database, which dates back to 1962, found that only 0.45% of them noted fatigue as a cause (Price 2009). Price concluded that analysis of this database shows that it drastically underestimates the role of fatigue because accident investigation methods did not include adequate methods for assessing whether fatigue was a potential contributor. Caldwell (2009) conducted a search of the scientific literature and other resources to explore the impact of fatigue on aviation safety; he found no other studies that estimated the percent of aviation accidents that involved fatigue.

Although pilots and crew have been the primary focus of concern in the aviation sector, fatigue among aviation maintenance personnel may be a concern as well. However, data to assess the extent to which fatigue poses a hazard to aviation maintenance do not exist. At best, one study estimated that approximately 12% of major aircraft accidents and 50% of engine-related flight delays and cancellations worldwide are due to maintenance deficiencies (Marx and Graeber 1994). That study only points to the fact that aviation maintenance may have an operational impact, but it does not necessarily implicate fatigue as being responsible for maintenance issues. However, aviation maintenance personnel have reported fatigue to be one of the most prevalent causes of accidents and deficiencies (Hobbs and Williamson 2000).

Rail

The rail sector has long recognized fatigue to be a concern. In fact, the first "hours of service" (HOS) regulations in the United States were established in 1907 for the rail industry. The 2008 head-on collision between a Union Pacific freight train and a Metrolink commuter train in the Chatsworth district of Los Angeles, California, heightened this concern due to the likelihood that fatigue was a major contributor to the accident. HOS have been further restricted and recently the U.S. Congress mandated fatigue management be adopted in the railroad industry.

The Chatsworth accident and the mandate from Congress spurred several studies. A recent study indicated that between 1996 and 2002 accidents involving fatigue or alertness occurred on average three times per year (Oman et al. 2009). Gerson et al. (2009) screened a sample of railroad workers using the Epworth Sleepiness Scale. More than 40% of the respondents reported that they experienced Excessive Daytime Sleepiness, which is significantly higher than the estimates (ranging from 2 to 8%) for the general population. Rail workers experience irregular schedules and sometimes backward shift rotations. Research has demonstrated that both these practices aggravate fatigue by hindering an individual's ability to biologically adjust to disruptions of their circadian rhythms.

The Federal Railroad Administration (FRA) validated and calibrated a biomathematical fatigue model to assess fatigue in the rail industry. Examining the 30-day work histories of locomotive crews prior to 400 "human-factors" accidents and 1,000 "nonhuman-factors" accidents, this assessment found a strong relationship between crew fatigue scores based on the biomathematical model analysis and the probability of a "human-factors" accident (Hursh et al. 2006).

Alerter systems have existed in locomotives for approximately 15 years but these systems have proven to be inadequate. The alerter system requires the locomotive engineer to hit a button every few minutes (the frequency increasing or decreasing depending on the extent of the potential safety hazards given the time and place) or an alert is sounded. The recent study by Oman et al. (2009) found that approximately 70% of fatigue-related accidents involved alerter equipped locomotives. This finding suggests that fatigued persons are able to hit a button every few minutes and that this action is insufficient to keep them alert. Locomotive engineers have reported that this motion becomes so habitual that they sometimes move their arms to push the button when they are sleeping at home in their beds (Oman et al. 2009). New locomotives will have a positive train control system installed. The rail industry is investigating whether other technologies might also be beneficial in new locomotives or for scheduling purposes (Oman et al. 2009).

Military and Space

Fatigue has been a long-term concern for the military and the space sectors in the United States and other countries. Each of the U.S. military branches has a division that conducts, sponsors, and reviews research on fatigue and tests technologies and methods to manage fatigue. These efforts are typically part of broader human factors initiatives. Military research and assessment efforts have focused particularly on fatigue of the war-fighter during sustained operations and, in collaboration with the non-military sector, on fatigue in transportation modes (land, air, and sea). The military has focused particularly on methods for predicting fatigue and its impacts, countermeasures including pharmaceuticals, and on incorporating fatigue in operations planning and management (Caldwell et al. 2009; King 2005; Storm 2008; Kronauer and Stone 2004). The military has also emphasized examination of the effects of fatigue on team performance (see for example, Darlington et al. 2006) and on performance in complex, multisystem environments (Lawton et al. 2005).

In related work, the U.S. military has invested heavily in the development of human performance modeling. As part of this effort, the U.S. Department of Defense funded a project by the Sandia National Laboratories to develop a model of soldier fatigue and its potential impacts on a "system of systems" that better reflects the operational context than previous efforts that focused only on a single system (for example, cockpit operations) (Lawton et al. 2005). The military branches have monitored or collaborated in many of the efforts to develop predictive models that better represent the complex operational environment and individual variability, including the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) and the Fatigue Avoidance Scheduling Tool (FAST) models.

Shift Schedule and Observed Risk of Injury

Information on fatigue risk factors associated with injuries and "accidents" or incidents at work from actual occupational settings offers good face validity. However, because these are not controlled experiments, there is always the risk of unknown biases and confounding factors. To the degree that these studies can avoid such pitfalls, they offer observed relative risks which take into account real-life reactions and strategies for managing various shift and extended work-hour situations. Thus, for example, whether workers choose sleep or socializing during recovery periods is accounted for and averaged out over each workforce. Because it is unlikely that these "recovery" factors will be controlled under real highway construction activities, these studies, if well conducted, offer a good estimate of how shift and extended work impact safety.

Among all publications reviewed, a series from Folkard and colleagues at the Université Paris Descartes, Paris, France, stand out as providing convincing risk factors across a range of industries (Folkard and Tucker 2003; Folkard and Åkerstedt 2004; Folkard and Lombardi 2006; Folkard et al. 2006). These researchers carefully screened published industrial studies from the 1960s through 2001 for sufficient information and potential confounding factors, including changes in work by shift, numbers of workers per shift, availability of first aid, and factors impacting reporting by shift. The researchers conducted meta-analyses, but also demonstrated consistency between the individual studies.

These studies contain a number of important findings, summarized here. The risk of injury increases in a linear fashion from morning (baseline) to afternoon (18.3%) to night (30.4%). Risk also increases by number of consecutive days on shift, and the risk increase is substantially greater for night versus day shifts. Thus, increased risks (compared to the first day on shift) for the second, third and fourth consecutive days are as follows: for day shift, 2%, 7%, and 17% higher; for night shift, 6%, 17%, and 36% higher. Increased risks associated with increased hours worked per week vary by how these hours are organized. Examples are given for 48-h and 60-h weeks (compared to five 8-h shifts, i.e., a standard 40-h week). In a 48-h work week, increased risk associated with six 8-h shifts is 3% [relative risk (RR) 1.03], and for four 12-h shifts, 25% (RR 1.25). In a 60-h work week, increased risks are even greater: 54% for six 10-hr shifts (RR 1.54); and 62% for five 12-h shifts (RR 1.62). Finally, risk of injury increases linearly with time since last break, by 110% (RR 2.1) at 90 to 120 min compared with risk at 0 to 30 min.

Two other studies in the series conducted at Brigham and Women's Hospital examined fatigue-related injuries and accidents among medical interns. In one study, they examined the risk of self-reported percutaneous injuries (PI) among participating interns doing extended work (day shift after night shift) versus non-extended work (day shift with no previous night shift); and night work versus day shift (Ayas et al. 2006). Results were reported per 1,000 opportunities. During extended versus non-extended shift, interns reported 1.310 versus 0.757 PI/1,000 (OR 1.61, 95% CI 1.46 to 1.78), and during night versus day shift, interns reported 1.48 versus 0.70 PI/1,000 (OR 2.04, 95% CI 1.98 to 2.11). The results from both studies are much less specific than those reported by Folkard and colleagues. However, they provide evidence for the significant impact of both extended work shifts and type of shift on performance and safety.

Another study examined the risk of motor vehicle accident (MVA) as a function of time on shift (Barger et al. 2005). They found that extended shifts of 30 h were common and that interns reported significant sleep restriction during extended shifts. Interns were 2.3 times more likely to report an MVA while driving home from extended shifts compared with shorter shifts, and 5.9 times more likely to report a near miss under the same conditions. Moreover, each additional extended shift per month was associated with a 9.1% increase in the monthly risk of MVAs overall and a 16.2% increase in the monthly risk of an MVA during the commute home after an extended shift. Findings from another case-crossover design study in Italy suggested an association between long hours at work or without sleep in the prior 24 h and elevated risk for MVAs (Valent et al. 2010).

The Construction Industry

Injury and Fatality Rates

The U.S. construction industry is among the most hazardous for workers. In 2008, construction laborer was one of seven occupations where the rate of injury requiring time away from work was greater than three times the all-worker rate [Bureau of Labor Statistics (BLS), 2009a]. This rate was estimated at 383.1 per 10,000 full-time workers for construction laborers, similar to the rate for truck drivers (362.0), and substantially higher than the rate for retail salespersons (90.1), though lower than the rates for occupational groups containing nursing and moving freight by hand (449.0 and 440.3, respectively). The leading cause of these injuries among construction laborers was contact with object or equipment (40%). Of private-sector industries, construction accounted for 11% of all illnesses and injuries requiring time away from work (BLS 2009a). The construction industry experienced the greatest number of fatal occupational injuries in 2008 (969), and the fourth highest rate, 9.6 per 100,000 full-time workers, nearly three times the all-worker rate of 3.6 (BLS 2009b).

Hispanic Workers

Hispanic construction workers have elevated risks for occupational injuries and fatalities. In 2005, Hispanics made up 23% of construction employees overall and 27% of employees in construction production; also, 75% of the 2.6 million Hispanics employed in construction overall were foreign born (Center for Construction Research and Training 2008). An analysis of national survey data from 1996 to 2002 found that Hispanics employed in construction were significantly more likely to work in production occupations or to be temporary workers than were non-Hispanic whites; they were also significantly more likely to have had a work-related injury, even when the effects of occupation and education were taken into account (Dong et al. 2010). In 2000, Hispanic construction workers were nearly twice as likely to die from occupational injuries than non-Hispanic workers (Dong and Platner 2004), and between 2003 and 2006 the construction industry led occupational deaths among Hispanics at 34% (Centers for Disease Control and Prevention 2008). In addition, occupational deaths among Hispanic construction workers may be undercounted due to these workers' overrepresentation in the temporary or informal sector workforce, whose members are not typically eligible for workers compensation or other benefits (Dong and Platner 2004). Finally, communication barriers between mostly non-Hispanic managers and a growing Hispanic workforce, many of whom report not speaking English comfortably, are a significant challenge to efforts to improve workplace safety (Center for Construction Research and Training 2008; Harrington et al. 2009; Centers for Disease Control and Prevention 2008).

Road Construction

Workers at road construction sites are at risk from both automobile traffic passing by and from construction equipment and car and truck traffic on the site. From 1995 to 2002, according to the BLS Census of Fatal Occupational Injuries, 844 workers were killed while working at road construction sites (Pegula 2004). Of these, 509, or about 60%, were struck by a vehicle or mobile equipment. Of those 509 fatalities, only 28% involved automobiles; the majority of workers were struck by trucks (54%), and others were struck by construction machinery (12%). Almost half of workers killed by vehicle or mobile equipment were flagging or directing traffic (18%) or walking in or near the roadway (28%) when they were struck. Another source indicates that of all traffic work zone fatalities, 71% were the result of the worker being struck by a vehicle working in the zone or entering the work zone (Center for Construction Research and Training 2008). An analysis of New York State Department of Transportation construction project accidents from 1990 through 2001 found that 22 accidents involving worker fatalities and 356 accidents involving hospitalizations of workers occurred in the construction work area, as compared with 14 and 91, respectively, in traffic (Mohan and Zech 2005). The leading source of fatal and hospital-level accidents in the construction area was large equipment or worker vehicle (45.5% and 38.3%, respectively). A study of accident data in the state of Illinois concluded that highway construction workers have approximately five times more risk of an occupational accident during nighttime versus daytime work (Arditi et al. 2007).

Fatigue and Construction Injuries

While there exists a volume of research demonstrating links between extended work hours, overtime, and shift work with occupational injuries and with motor vehicle accidents while commuting home, research on the relationship between fatigue and injuries or fatalities specific to the construction industry is limited. Two different studies using the same national survey dataset (National Longitudinal Survey of Youth) found links between workplace injuries and work schedule among construction workers. In the first, construction workers working more than 8 h per day (OR 1.02), more than 50 h per week (OR 1.98), or starting work before 7:00 a.m. (OR 1.28) were all found to be more likely than others to report a work-related injury after adjustment for other factors (Dong 2005). Significant findings from the second study also include a positive association between overtime work and likelihood of injury relative to not working overtime (OR 1.48), as well as increased risk of injury related to working the evening shift compared with working the day shift (OR 2.86) (Dembe et al. 2008). An analysis of workers compensation claims and payroll data for 2,843 construction contracts associated payroll overtime of >20% with higher rates of non-lost-time injuries among workers (Lowery et al. 1998). Two related studies linked sleep disorders (determined from self-reported factors) with elevated risk for work-related injuries requiring substantial time off work or hospitalization and for injuries from moving objects, which the authors speculated could be due to impaired vigilance (Chau et al. 2004; Chau et al. 2004).

None of the studies of construction workers, and only a few occupational studies, were able to establish timing of injuries in relation to work or sleep schedule, or to directly measure neurobiological factors underlying fatigue. However, these studies do provide some contextual evidence that supports the hypothesized relationships among work scheduling, fatigue, and adverse safety outcomes. Work schedules may affect the neurobehavioral performance of construction workers through circadian influence, affecting safety. Also, extended duration at work and poor sleep quality may each affect the safe performance of tasks because of decreased opportunity for sleep. Construction laborers may be at increased risk for occupational injury and death for reasons related to both a riskier-than-usual work environment, which may be especially hazardous for fatigued workers through impaired vigilance, and scheduling practices and social norms, which can contribute to experience of fatigue at work. An ethnographic study of construction workers indicates that both management and personal pressures to work extended hours are substantial, which workers recognize can lead to elevated risk of adverse events at work (Goldenhar et al. 2003).

Integrated Fatigue Risk Management Approaches

The data reviewed above, as well as the general trend in fatigue and sleep research, suggest that the best way to address the problem of fatigue in operational settings is with an integrated approach. That is, no single measure or intervention is likely to be particularly effective, but requires a combination of training and education, schedule risk assessment, healthy sleep, and fatigue countermeasures (Rosekind et al. 2006; Caldwell et al. 2008). This section reviews the elements of integrated approaches based on recent reports of implementations in operational settings.

Background

Integrated approaches to fatigue management trace their origin to the National Aeronautics and Space Administration (NASA) Ames Fatigue/Jet Lag program, later renamed the Fatigue Countermeasures Program. This nearly 20-year research and outreach program performed groundbreaking research on the causes and consequences of fatigue in aviation operations, and it established best research practices that are carried out today. Additionally, an education and training module was developed and presented to more than 2,500 individuals, and the material in the program served as a basis for individual airlines to develop their own alertness management systems. Many of the aspects of integrated approaches, such as education and training, countermeasures, and healthy sleep habits were originally developed and articulated in this program. Currently this program is not supported within NASA, but the website, at human-factors.arc.nasa.gov, is an excellent resource for the various research studies and interventions evaluated, and the program was enormously influential in helping to establish similar activities across the U.S. DOT.

Components of Integrated Fatigue Management

Caldwell et al. (2008) delineate 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. There has been a tendency over time to think of fatigue simply as a "state of mind" that can be overcome with "professionalism" or "endurance." However, these philosophies lead to undesirable results from persons working to the point of safety vulnerability and beyond (e.g., falling asleep on the job). Thus, establishing this understanding concerning the physiological basis of fatigue, how it is manifest in work situations, and what can be done about it are the key components of a training and education program. A variety of material exists for an organization to create its own educational programs, such as the Fatigue Management Reference developed by the DOT Human Factors Coordinating Committee (McCallum et al. 2003). Additional elements described by Caldwell et al. (2008) include

- Recognition of individual differences in fatigue vulnerability;
- Strategies for improving work and rest scheduling;
- Techniques for optimizing sleep (including good sleep habits and use of sleep inducing medication when necessary);
- Techniques for optimizing circadian adjustments; and
- Techniques for temporarily mitigating fatigue ("countermeasures" including rest breaks, napping, and judicious use of caffeine).

Caldwell et al. (2008) delineate the major factors in operational environments that are associated with fatigue (Table 2.4); these factors operate across a range of work environments. The challenge for researchers and practitioners in specific operational domains is to discover how these factors manifest themselves and impact the workforce.

Implementation of integrated alertness or fatigue management programs has been shown to have measurable, beneficial impacts. Rosekind et al. (2006) report on the development and evaluation of an alertness management program for a major commercial airline. The program included education involving the basics of sleep and fatigue, alertness strategies, assessment of schedule risks, and testing of alternative schedules.

Table 2.4. Factors Leading to Fatigue

Factors Leading to Fatigue
Long hours in a given shift
Working long shifts several days in a row
Work and/or sleep schedules irregular or unpredictable
Critical tasks performed during circadian low points (night, mid-afternoon)
Insufficient sleep immediately prior to work shift
Insufficient sleep for several days prior to work shift
Work requires sustained attention
Work environment is dimly lit and quiet
Physical or mental stress present (e.g., high-speed traffic, noise, and vibration from heavy equipment)

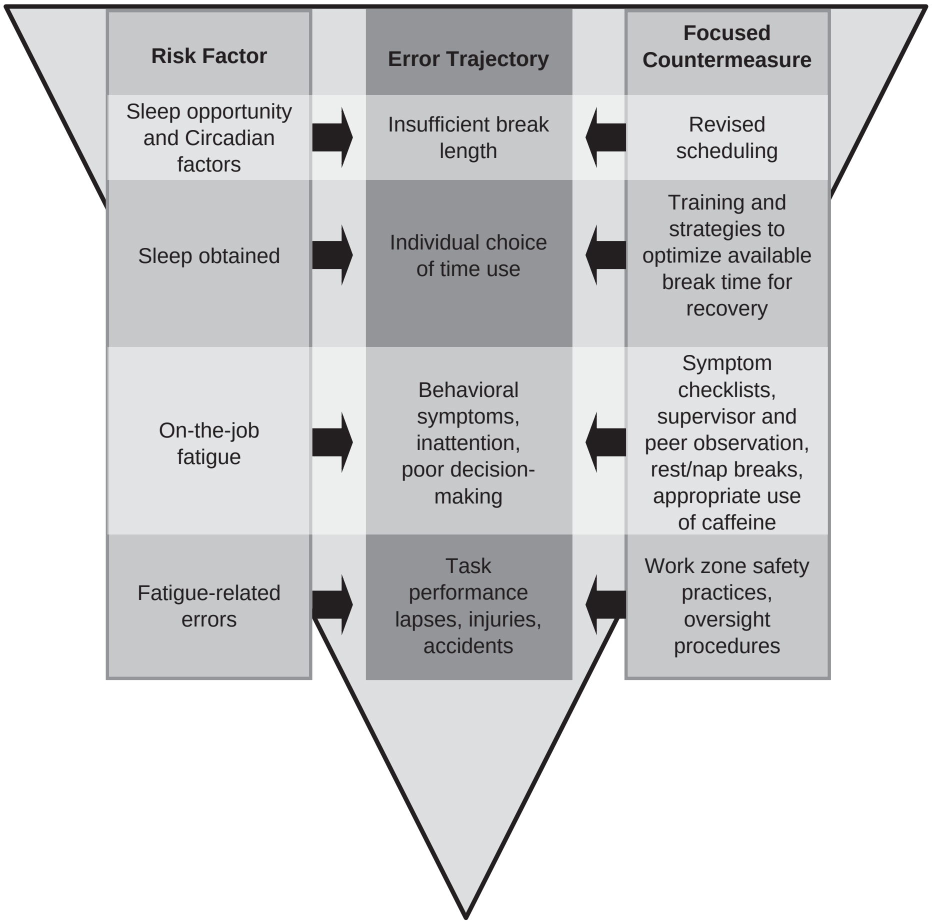
Pilots were measured on a variety of variables before and after the alertness program intervention (knowledge, sleep duration, PVT performance), and the results indicated that all measures improved significantly following the implementation of the alertness management program. In particular, following the program intervention, pilots slept an average of 1 h and 9 min longer while on flight trips.

Dawson and McCulloch (2005) discuss managing the opportunities for sleep as a key component of managing fatigue in the operational setting. Their concept is based on a hierarchical model of hazards, error trajectories, and control mechanisms. At the base of the model is the opportunity for sleep and the average sleep obtained; the key control mechanisms for this level are work-hour rule ("hours of service" or HOS in their model) and aggregate prior sleep/wake modeling (PSWM) to assess the likelihood of fatigue. They focus particularly on prior sleep in the past 24 and 48 h, as this would be relatively simple to measure from employees in an operational setting. The opportunities for intervention, indicated by the breadth of the inverted pyramid in the figure, are more numerous at the base, and become increasingly more difficult to implement at higher levels on the risk trajectory. At increasing levels of the risk trajectory, more refined data and control mechanisms are used, and the opportunities for intervention are less available. Based on various modeling and empirical studies, Dawson and McCulloch suggest that sleep reduction of less than 5 h in the previous 24, or 12 h in the prior 48 is likely to lead to impairment. An adaptation of Dawson and McCulloch's model includes focused countermeasures specific to the operational environment of road construction that address different levels in the error trajectory (Figure 2.2).

Fatigue Countermeasures

Hours of Service (HOS)

Most fatigue-oriented regulations in the United States consist of HOS limits and rest break requirements. For example, the current HOS regulations for the U.S. DOT specify both driving time limits as well as an hours-off component; that is, after



Adapted from Dawson and McCulloch 2005.

Figure 2.2. Fatigue risk trajectory linking risk factors, fatigue impacts, and potential classes of countermeasure.

34 consecutive hours of off-duty time drivers can begin a new 7-day period during which they can drive or be on duty for a cumulative total of 70 h. (On-duty time can include non-driving time, such as rest breaks and time loading or unloading, time spent at weigh stations, etc.) This means the 7-day clock restarts after a 34-h off-duty period. In some sectors, these regulations have not been updated for decades. These early regulations did not have a strong scientific basis (Jackson et al. 2009; Hursh 2009). Regulators, fatigue scientists, and technology developers are attempting to address this situation.

Work Schedule Assessment and Management

Until recently, biomathematical models of the sleep–wake cycle and fatigue have primarily been tools for basic research, seeking to integrate the empirical data obtained from studies by researchers from a wide range of disciplines. However, applied biomathematical fatigue technologies are now being used to predict the prevalence and extent of fatigue for work groups and to evaluate alternative work and non-work schedules. These biomathematical tools do not directly measure individuals' biological processes; instead, they use projected or past work hours and work schedules to predict workforce fatigue levels based on how these factors, on average, are expected to impact the sleep and wake cycle. Torgovitsky et al. (2009) are building a model specifically designed to assess an individual's response (rather than a group average response) to work schedules. Others have proposed adaptive modeling techniques for individualized fatigue predictions (Van Dongen et al. 2007).

Researchers have historically used biomathematical fatigue models to investigate how endogenous sleep and wake processes correlate with indications of fatigue and/or performance impairment. A key goal was to improve the validity of these models with respect to predicting, detecting, and estimating fatigue. Tools now exists that use biomathematical fatigue models to evaluate alternative work schedules and optimize schedule solutions by balancing fatigue-informed practices and business needs. These biomathematical scheduling technologies provide feedback regarding "time-at-risk" for particular schedule solutions and predict the likelihood of fatigue for the work group. Individual variability on multiple parameters has thus far thwarted efforts to develop models capable of predicting fatigue for a particular individual. Advanced scheduling tools incorporate additional factors besides work schedules, such as workload, nature of the task (especially monotony), environmental conditions, and naps.

Napping

Naps are among the most efficacious countermeasures for fatigue, as they contribute approximately hour-for-hour to total amount of sleep during the day (Mollicone et al. 2008). Naps thus contribute to reducing the homeostatic pressure for sleep in proportion to nap duration (Sallinen et al. 1998; Schweitzer et al. 2006). Napping is particularly effective when scheduled defensively, that is, before sleep loss is incurred (Dinges et al. 1986; Cote and Milner 2009). Very brief naps (10 to 20 min, sometimes called "power naps") may also be effective to counteract fatigue (Brooks and Lack 2006), but the duration of the alerting effect of such brief naps has not been determined and is probably relatively short. A side effect of napping is the potential for sleep inertia.

Caffeine

The most widely used operational countermeasure for fatigue is caffeine (Roehrs and Roth 2008), consumed through a variety of beverages and foods (of widely varying dosing) and even available in the form of a precisely dosed, fast-acting gum (Kamimori et al. 2002). Higher doses increase the alerting effect of caffeine, but the marginal benefit becomes smaller the higher the dose (Kaplan et al. 1997). For greatest effectiveness, caffeine should be used judiciously at the times when it is needed most, as repeated dosing reduces its efficacy (Roehrs and Roth 2008). Furthermore, with repeated use, tolerance builds up, reducing caffeine's effects in habitual users and leading to withdrawal effects when one's daily dose of caffeine is not available (Nehlig 1999). Carefully timed, strategic combinations of caffeine with napping may constitute a countermeasure approach that is superior to either caffeine or napping alone (Schweitzer et al. 2006). However, if caffeine is taken relatively close to bedtime, it may interfere with sleep quality, duration, or both, thereby reducing the homeostatic recuperation of sleep (Drake et al. 2006) and thus becoming counterproductive.

Motivation

Incentives and other sources of motivation can help with the effort to stay awake and maintain performance in the face of sleepiness (Horne and Pettitt 1985), although there is a limit to how long this compensatory effort can be maintained until the endogenous neurobiological drive for sleep takes over (Doran et al. 2001). Difficult to control because of numerous external influences potentially involved, motivation in most work environments is not a reliable countermeasure for fatigue.

Light

Light exposure affects the timing of the circadian process in a phase-response (Minors et al. 1991) and dose-response (Boivin et al. 1996) manner. 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, whereas light in the morning advances circadian timing. Daily exposure to (morning) light in individuals on a normal daytime schedule serves to keep the circadian process synchronized (entrained) to the 24-h clock (Beersma et al. 1999), but in night and shift workers, light exposure tends to disrupt circadian rhythmicity (Santhi et al. 2008). Yet, planned light exposure patterns can be helpful in managing the circadian process and mitigating fatigue (Lee et al. 2006). Laboratory studies of simulated night shifts have yielded evidence that exposure to intermittent bright light pulses during the shift may be somewhat successful in delaying circadian rhythms and improving reaction times (Smith et al. 2008). Light exposure also has an acute (but highly transient) alerting effect (Cajochen 2007), which is particularly strong for short wavelengths (i.e., from blue and full-spectrum light sources) (Lockley et al. 2006).

Summary and Conclusion

Biological and environmental factors influence an individual's need for sleep. Fatigue is a function of both time awake (the homeostatic process) and time of day (the circadian process). Work-related fatigue is therefore a function of shift duration and shift timing: Long shifts may not provide adequate opportunity for rest; work at odd hours may require sleep during the day, resulting in poor sleep quality and less sleep obtained. Sleep deprivation affects both sensations of fatigue and cognition. Cognitive effects can include degraded alertness, difficulty concentrating, forgetfulness, and confusion as well as degraded performance on specific tasks. Accumulated sleep deprivation can result in severe performance decrements. Individuals vary in their need for sleep, and therefore, in their responses to sleep loss. Sleep loss can only be countered by obtaining additional sleep; severe sleep loss can require substantial recovery time. Following sleep deprivation, subjective ratings of fatigue return to baseline more quickly than does cognitive performance.

Studies of the effects of restricted sleep in operational settings demonstrate that task performance is degraded with sleep loss, resulting in, for example, higher rates of medical error, unsafe driving behaviors, and motor vehicle accidents. Fatigue has been implicated as well in aviation and rail accidents. Shift workers are particularly prone to fatigue-related injuries if they work night shift, extended shifts (10 or more hours), or work weeks longer than 40 h. Construction workers have elevated risks for occupational injury and fatality relative to most other occupational groups. In construction, the likelihood of occupational injury is higher for those working extended shifts, night and evening shifts, and weekly overtime. A work culture that expects workers to be available for overtime work likely contributes to the relatively high risk of adverse safety outcomes.

An integrated approach to fatigue risk management is essential and includes instilling in workers and management an understanding of the nature of fatigue. Components of such an approach include improving work/rest scheduling (*strategic*), developing countermeasures for temporarily mitigating fatigue (*immediate*), such as caffeine and napping, as well as appropriate training and monitoring for symptoms of fatigue and reduced performance.

Rapid renewal highway construction projects are likely to become more common in the future as planners strive to work around dense and growing populations with increasing traffic volumes. Understanding how the scheduling constraints of rapid renewal projects affect worker fatigue, and therefore productivity and safety, is key to developing a fatigue management plan that provides effective organizational- and individual-level countermeasures for adverse safety outcomes.

CHAPTER 3

Field Study of Fatigue Factors in Rapid Renewal Projects

Introduction

To obtain a more detailed and practical understanding of the nature and severity of worker fatigue in rapid renewal highway construction, the team carried out a field study using survey and subject matter expert (SME) interview techniques. This chapter describes the specific methods for the field research, data analysis, and findings.

Recruiting Research Participants

Recruiting for field research participants was based on the initial contacts to state DOTs provided by the TRB steering committee. From each of the six states solicited for involvement (New York, Florida, Washington, Utah, California, and Illinois), the team identified candidate projects as described in Appendix A, along with key state DOT contacts. These DOT contacts were further solicited for prospective participation as working group members, and they were requested to provide contacts with the contractor companies for those projects that were still in the active phase of construction. This was followed by an initial e-mail solicitation to the construction company project managers, and followed up with telephone discussions with those companies expressing interest in supporting the research.

The team had obtained agreement on the initial set of projects in July 2010. Delays associated with project plan approvals and Institutional Review Board reviews required re-constituting the sample in February 2011. The team considered attempting data-gathering among managers and work crews for projects that had concluded, but determined that it would be too difficult to locate workers who had moved on to other projects and, also, that the survey and interview data these workers could provide about concluded projects would be less useful when collected retrospectively. The final set of projects for conducting field research, and the time periods during which it was conducted, is as follows:

- Florida, SR-50: March 2011
- New York, I-287: May 2011
- Washington, SR-520: Feb., March, and June 2011

Each of these projects is described in greater detail in Appendix A. For each of the projects, the team attempted to schedule field work in such a way as to permit survey data collection from workers on both day and night shifts. Due to construction task sequencing, this did not occur on any project. The Washington state SR-520 project, however, did provide the opportunity to gather survey data from respondents who had just participated in a 55-h closure weekend.

General Field Work Methodology

Procedures

Data collection began at each project with a general orientation to the job site, which included driving to the site with the contractor and a review of work completed, work in progress, and makeup and distribution of crews across the site. In general, the team relied on contractor and DOT supervisors for access to their employees. SME interview respondents were obtained through snowball sampling; after the team interviewed the primary on-site contact for the project, the team solicited recommendations for other personnel who could offer a systematic perspective on an aspect of the project. SMEs were given a briefing document that provided an overview of the research and outlined their rights as research subjects. Interviews were usually conducted individually (two interviews included pairs of respondents), lasted between 30 and 60 min, and were audio recorded and transcribed. Interviews with three SMEs were conducted by telephone.

The bulk of recruitment for the survey was performed by supervisors and, in one case, the safety officer for the project. This method of recruitment was necessary in order to both ensure the safety of the research team and to minimize disruption to the work, and the team allowed supervisors to determine the best method given their particular situations. About half the time, contractor supervisors drove research team members to specific areas of the job site, introduced them to workers, and then allowed them to recruit from among the available workers in that area; in these cases the team tried to interview all available workers who consented. At other times, workers were brought to the field office and were surveyed there, sometimes during and sometimes before work hours. Survey respondents were selected opportunistically, though the team did communicate some basic sampling guidelines (e.g., the desirability of obtaining a range of roles and occupational types), and supervisors accommodated the team's requests when possible.

Survey respondents gave informed consent before beginning the survey. Surveys were conducted with individual respondents in private or, if total privacy was not possible (e.g., on the side of the road), out of the hearing of others. When possible, two team members conducted the surveys, one person reading questions and the other noting responses, but for about half the surveys one research team member read and took notes simultaneously. The process of consenting and administering the survey took 30 to 35 min.

Survey and interview respondents who were not DOT employees were compensated $50 for their time; DOT employees were not permitted to accept compensation. The survey instrument and interview guide are provided in Appendix B.

Sample

The team conducted interviews with 20 SMEs and administered the survey to 47 respondents, including both management and labor (Table 3.1). Note that six SMEs were also surveyed, for a total of 61 unique respondents. Interview respondents came from a broad range of occupational types and included project managers, construction managers, project and field engineers, general superintendents, and inspection managers. Among these, six were state DOT representatives and 14 represented contractors and subcontractors. All respondents had worked on projects with rapid renewal scheduling characteristics in the past.

Table 3.1. Interview and Survey Respondents by State

	Interview Respondents	Survey Respondents	Total Respondents
Florida	3	18	19
New York	5	14	18
Washington	12	15	24
Total	20	47	61

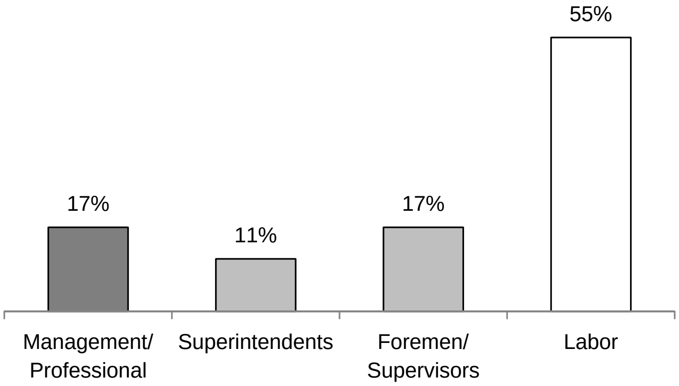


Figure 3.1. Occupational type, survey respondents (n = 47).

Survey respondents were also sampled from a range of roles. Respondents were broadly categorized as management/professional, superintendents, foremen/supervisors, or labor (Figure 3.1), with labor making up the largest group in the sample. Respondents were also asked to identify all of the activities they performed regularly, reporting their activities as follows: seven (15%) engineering, seven (15%) inspection, 12 (26%) labor, 14 (30%) operators, 10 (21%) traffic control, and five (11%) truck driving. The majority of respondents were paid an hourly wage and approximately one-third overall were union members (Figure 3.2). The level of work experience in this sample was fairly high: 32 (68%) had more than 10 years' experience, and 12 (26%) more than 25 years' experience (Figure 3.3).

Key Fatigue Exposure Measures: Survey

The survey included several measures of fatigue exposure, based on characteristics of reported work and sleep schedules. As used in the present study, *exposure* refers to the degree to which individuals have worked schedules that affect their

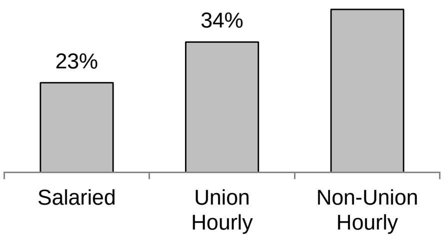


Figure 3.2. Pay structure, survey respondents (n = 47).

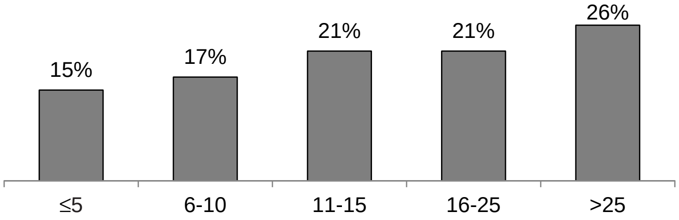


Figure 3.3. Years' work experience in highway construction, survey respondents (*n *= 47).

sleep opportunity. Two direct work schedule measures used were (1) the number of hours worked one week prior to the survey and (2) the longest period of consecutive days worked on the project without a day off. Two sleep schedule measures used were hours of sleep in the prior 24- and 48-h periods. A fifth fatigue exposure measure used PSWM (Dawson and McCulloch 2005) to predict each respondent's risk for fatigue-related error at the end of the work day on the day they were surveyed. The last three measures were derived from a 48-h work-sleep calendar and typical commute time. For the fifth measure, respondents were considered at risk for fatigue-related error if their 48-h calendar indicated (1) they had received fewer than 5 h sleep in the prior 24 h, (2) they had received fewer than 12 h sleep in the prior 48 h, or (3) their number of hours awake at the time they expected to arrive home on the day of the interview exceeded the number of hours they had slept in the prior 48 h. Whether the respondent was currently working night shift would have been a key fatigue exposure measure; however, all respondents were working day shift at the time they were surveyed.

Key Fatigue Experience Measures: Survey

Exposure, as described above, influences the experience of fatigue. The team used three measures of fatigue, including two validated scales and a composite measure of respondents' reported difficulty remaining awake at work. First, the team used the Epworth Sleepiness Scale (ESS) (Johns 1991), a validated scale used to evaluate excessive daytime sleepiness. Respondents were instructed to rate their likelihood of falling asleep in eight different situations; ratings were summed for a total score. ESS scores greater than 10 indicate abnormal daytime sleepiness. Second, the Swedish Occupational Fatigue Inventory (SOFI) (Åhsberg et al. 1997) is used to compare relative factor loadings on five fatigue components across occupations; here the team used the sleepiness subscale to measure fatigue. Respondents were asked to rate how well each of several words described how they felt at the end of the day; item ratings are averaged to provide an overall sleepiness measure. Third, respondents were asked: (1) whether they had ever fallen asleep on their current job site; (2) whether they had even been afraid they might fall asleep on their current job site; and (3) whether they regularly had difficulty staying awake during their commute home. Respondents who answered "yes" to any of these were considered to have had a sleepiness event at work.

Countermeasures, Training, and Attitudes: Survey

Respondents were asked to report on fatigue countermeasures they used at work or on work days, such as napping ("Do you ever take naps on your lunch break?") and caffeine use ("Do you drink any beverages containing caffeine on days that you work?"). They were also asked two questions about fatigue safety training they may have received ("Is fatigue a topic covered in your organizational safety training?" and "Does your training include material on how to get a good night's sleep and reduce or avoid fatigue on the job?"). Respondents were also asked questions to gauge attitudes about work-related fatigue (level of agreement with the statements: "fatigue on the job is really not a problem—just something you can 'muscle through'" and "fatigue at work is a safety problem").

Analytic Plan and a Natural Experiment: Survey

Given the manner in which survey respondents were recruited, the resulting sample is a convenience sample. This kind of sample is appropriate for an exploratory study, particularly in a population that is continually in flux and, therefore, extremely difficult to identify in advance. Appropriate analytic goals for this kind of sample include establishing the range of responses and making basic comparisons when warranted. The sample included a group of nine respondents (laborers, foremen, and supervisors) who had just finished working a 55-h weekend closure at the time they were interviewed. The weekend closure had involved 12-h day and night shifts constituted from the regular work crews. The inclusion of these respondents made possible a kind of natural experiment, wherein their fatigue outcomes under a recent "extreme" schedule condition could be compared with fatigue outcomes in other groups who had not recently experienced an extreme schedule. Comparisons are, therefore, provided for the key fatigue exposure and fatigue experience measures for the closure group relative to several relevant comparators; details are provided below.

Means and ranges are reported for continuous measures of fatigue exposure (e.g., consecutive days worked). Percentages are reported for dichotomous measures of fatigue exposure (e.g., at risk for fatigue-related error) and fatigue level (e.g., abnormal daytime sleepiness). Statistics for fatigue exposure and fatigue experience measures are reported for subsets of the sample to allow for basic comparisons based on the respondents' current or recent work schedule at the time of the interview: (1) worked recent closure weekend; (2) all others (no closure weekend); (3) among all others, those who currently work a 5 × 8 schedule; (4) among all others, those who had 2 full days' work (no time off) prior to interview. The last three groups (Groups 2 to 4) serve as comparators for those working the closure weekend (Group 1); Groups 2 to 4 are not mutually exclusive. Percentages using various individual countermeasures (e.g., caffeine, napping) are reported overall, and attitudes are reported overall and for a few key groups. Unless otherwise noted, statistics are not reported for groups of fewer than five respondents. Inferential statistics such as chi-squares or t-tests are not reported because of the exploratory nature of this study, which employs a non-random, convenience sample of workers.

SME Interview Results

Work Schedule Practices and Beliefs

Managers have diverse heuristics about schedule impacts on fatigue. At one site, a manager estimated at least a 50% productivity loss after 10 h, and noted that paying overtime for 12-h shifts was, therefore, counterproductive, though 12-h shifts in the short term could be useful. At another site, the project manager preferred to schedule 8-h rather than 10-h shifts, due to productivity decline, and at the third, management preferred to schedule an extra day (usually a Saturday) over extending regular shifts. Management at two projects reported that employees liked the longer or extra shifts, since (as one put it) "90%" of their annual pay is made in five to six months.

Fatigue Training

Fatigue training was cited by managers at all three projects, but they did not provide specifics. Safety training, while institutionalized on all projects the team visited, appeared to be largely informal and responsive to recent events or immediate work conditions. When discussing fatigue training, managers at two sites emphasized the importance of training for heat exhaustion and hydration during summer months. Managers at one site with a large proportion of Spanish-speaking laborers described cultural differences in dress and preferences for resting that they felt put immigrant laborers at greater risk for heat exhaustion.

Fatigue Assessment

Managers reported that they "know" worker fatigue when they see it. Indications managers cited that a worker is fatigued included erratic work, irritability, and declining social interaction, slowing down or just not working as hard, physical weakness, and appearing red in the face. One manager noted that workers became sloppier (more "mentally" fatigued) when performing monotonous tasks. The same manager expressed concern in particular about erratic work from operators, since they could "easily kill someone." Another manager said that he paid attention to variability in workers' ability to work extended shifts—some could do a lot of extra work while others could not—and tried to direct additional work to those he thought could handle it.

Fatigue Countermeasure Practices and Attitudes

Most fatigue countermeasures are applied informally. At two sites, managers reported that salaried personnel could expect the company to cover the cost of hotel rooms when circumstances warranted it, but no formal policy had been instituted on at least one of the projects. Managers were cognizant of the desirability of giving workers a full day off when switching between day and night shifts, and reported that they did this when possible, but no formal practices or guidelines were in place at any project. At one site, it was reported that management tried to make all such switches happen over a weekend. One manager said that he had instructed workers who appear fatigued when arriving at work to "sleep it off" in their car. Breaks are provided as necessary for heat stress and hydration. Informal comp time was sometimes used for salaried employees.

Managers were asked about napping at work—whether they had seen it and how they felt about it in their workforce. Most reported having seen it on occasion. Managers at two sites acknowledged that it was hard to argue that workers did not have the right to take naps on their lunch breaks ("it's their time") but they were uncomfortable with it. The general feeling was that workers should not be "that tired" and should arrive at work well-rested. One manager said he was worried that workers who napped on night shift would have difficulty waking sufficiently to continue work. This manager also disapproved of workers napping during down time, and gave the example of a truck driver waiting 30 min for a load. A manager at another project cited safety problems when workers napped "in the field."

Commuting and On-site Presence

Among other issues raised by management was commuting. On one project, commute times of 1.5 h each way or more were not uncommon, particularly among the salaried personnel. On this project, laborers tended to be drawn from the region immediately surrounding the project, while company management sometimes traveled long distances to job sites. There was concern that very long commutes contributed significantly to fatigue and also detracted from the ability of these personnel to respond to emergencies after hours. Related to this latter point, another manager cited an "on-call" effect,

Day	Cumulative Hour	Time	Event	Sleep Duration
1 – Friday	0	0600	Work in office	6 hours (prior night)
	12	1800	Return home, eat, no sleep	
	17	2300	Return to job site	
2 – Saturday	22.5	0430	Return home	
	25.5	0800	Sleep	
	29.5	1200	Wake	4 hours
	30	1230	Return to job site	
	40.5	2300	Return home	
3 – Sunday	42.5	0100	Sleep	
	46.5	0530	Wake	4.5 hours
	48	0700	Return to job site	
	60	1900	Return home	
	63	2200	Sleep	
4 – Monday	68.5	0330	Wake	5.5 hours
	69	0400	Return to job site	
	70	0500	Closure ends	

Figure 3.4. Work–sleep timeline for manager during 55-h weekend closure.

when he could not sufficiently relax while at home due to the likelihood that he might be called for problems. Several managers mentioned this as a fact of life in their chosen profession. Both issues relate to another point the team raised, which was whether there was a system of "coverage," wherein key personnel could expect others to handle calls or other concerns late at night, or to spell one another during periods of night work. The typical response was illustrated by one manager: "If I've got *him*, what do I need *you* for?"

Relevant to both the "on-call" effect mentioned above and the general lack of redundancy in supervisory staff, managers reported a tendency to be on site whenever work was taking place. During continuous closure activities this can lead to extremely extended periods of work and severe sleep disruption. Figure 3.4 illustrates the schedule for one manager during a continuous weekend closure, starting with his regular workday on Friday, with the closure beginning Friday evening and ending Monday morning.

This figure shows that during the course of the weekend closure, the manager is very sleep deprived and at risk for fatigue during the entire period. The work week following the closure is generally a standard schedule, so there is no off-work recovery time.

Survey Results

Sociodemographics

Of the sampled workers, four (9%) were women; only two (4%) were under the age of 25; 14 (30%) were aged 25 to 39; 16 (34%) aged 40 to 49; and 15 (32%) aged 50 and older. Most were married (72%) and just under half had children under age 18 living in their homes (45%). The team estimated that eight respondents (17%) were not native English speakers.

Work Schedules, Rest, and Preferences

All survey respondents were working day shift when surveyed. Base schedules (i.e., excluding occasional weekend work) for the 36 hourly workers are shown in Figure 3.5; 5 days of 8-h shifts (a "5 × 8") was the most commonly reported schedule. Most of the respondents working this schedule were on a project in its final stages.

All but six out of 33 hourly workers with a preference reported preferring day shift to night shift, and the main reasons offered for this preference were less disruption to family life (44%) and a sense of "normalcy" (33%), which many defined as better sleep opportunity (19%). Reports of typical sleep obtained in a 24-h period averaged 2 more hours while working day shift compared with night shift, and even more

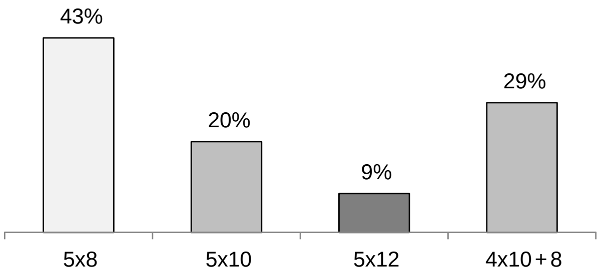


Figure 3.5. Base schedule, hourly workers (n = 36).

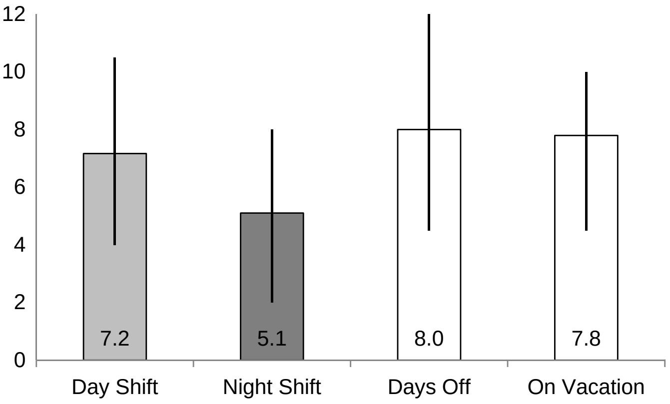


Figure 3.6. Typical hours sleep under varying conditions, mean and range (*n *= 24).

on days off (Figure 3.6). Only three hourly workers reported getting more sleep while working nights than while working days (9.4%).

Most hourly respondents reported standard meal (one 30-min) and rest (two 15-min) breaks, but then noted that breaks were actually discretionary, with many volunteering that they usually had plenty of time for breaks. With respect to days off, all but one respondent reported getting at least 36 h between shifts every time (76%) or nearly every time (22%) they got a day off. The mean shortest break reported between two shifts on the respondent's current job was 9.5 h (range: 0, 24), although for salaried respondents the mean as well as the maximum shortest break was somewhat lower (8.1 h; range: 4, 12).

Among hourly workers, 10 (28%) reported wanting to work more hours than they had in the prior 2 weeks, while seven (19%) would have preferred to work less (Figure 3.7). Desire for additional hours appeared to be negatively correlated with hours worked in the prior 2-week period, with respondents working 40 or fewer hours a week mostly wanting more hours (63%), those working more than 60 h mostly wanting fewer hours (57%), and two-thirds of those working between 40 and 60 h preferring "about the same." No salaried respondent wanted to work more hours, but nine of them (82%) reported preferring to work about the same amount as they had worked in the prior 2 weeks, which averaged about 52 h per week. One quarter of hourly workers reported working fewer than 12 months out of the year in highway construction.

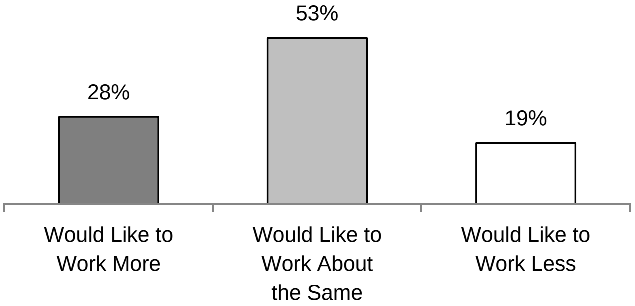


Figure 3.7. Desire for additional hours, hourly respondents (*n *= 36).

Fatigue Outcomes, Closure versus Others

Survey respondents reported excessive fatigue exposure with rapid renewal practices, in this case, a 55-h weekend closure at one site. The nine respondents who had worked the closure just prior to the survey reported nearly 73 h of work on average by the end of the closure Saturday, for example, by the end of Day 6 of what for most of them was a 12-day stretch (Table 3.2, Group 1). This group reported an average of 14 h sleep (ranging as low as 10 h) in the prior 48 h, and two-thirds of this group were at risk for fatigue-related error at the end of the weekend closure. By way of contrast, respondents who did not work a closure weekend immediately prior to the survey (Group 2) reported working an average of 25 fewer hours in the prior week, got an average of nearly 90 min more sleep in the prior 48 h, and only 11% were at risk of fatigue-related error at the time of the survey.

Respondents working the weekend closure also had higher fatigue levels than those who did not: One-third of those working the closure had abnormal daytime sleepiness relative to only 9% of others; and those working the closure had a mean SOFI score of 3.3 compared with 2.2 for all others. Also, two-thirds of the closure group had a sleepiness event on the project, compared with only about one-third of others.

Non-closure respondents with the least-intensive schedules, that is, a "traditional" 5 × 8 work week (Group 3), also reported lower rates of fatigue exposure and lower fatigue levels than those working the closure. They had worked nearly 34 fewer hours in the prior week and had gotten nearly 90 min more sleep in the prior 48 h, and their rate of being at risk for a fatigue-related error dropped to zero. None experienced abnormal sleepiness, their mean SOFI score was half that of the closure group, and fewer than half reported a sleepiness event.

Respondents in the group that had no shifts off in the prior 48 h (Group 4) were included as a comparison group in order to more closely match the recent work patterns of those who had just worked a closure. These respondents also reported substantially lower levels of fatigue exposure and fatigue level at the time of the interview compared to respondents who worked the closure, even though this group had worked more than 50 h, on average, in the prior week and reported an average of eight consecutive days at work as the maximum on their current project.

Table 3.2. Fatigue Exposure and Fatigue Experience by Type of Work Schedule

	Fatigue Exposure				Fatigue Level			
	Most Consecutive Days Worked on Project	Hours Worked Last Week	Hours Slept in Prior 24	Hours Slept in Prior 48	At Risk for Fatigue-Related Error	ESS, Abnormal	SOFI	Sleepiness Event on Project
Work Schedule Group	Mean (range)	Mean (range)	Mean (range)	Mean (range)	%	%	Mean (range)	%
1) Weekend Closure (*n*=9)	11.2 (6,12)	72.7 (63,90)	7.3 (5.5,13)	14.0 (10,20.5)	67%	33%	3.3 (0.2,9)	67%
2) All others (*n*=38)	6.4 (5,30)	47.4 (28,65)	7.6 (4.3,15.5)	15.3 (12,20.8)	11%	9%	2.2 (0,6.4)	36%
3) Others, 5×8 shifts (*n*=13)	5.9 (5,6)	39.1 (28,48)	7.5 (5,10.3)	15.3 (12,20.8)	0%	0%	1.6 (0,4.6)	44%
4) Others, no days off in prior 48 h (*n*=8)	8.0 (6,15)	51.5 (44,65)	7.7 (6.5,9.3)	15.5 (13.3,19.3)	13%	13%	2.8 (0.8,5.2)	43%

Weather and Fatigue

Nearly all respondents (89%) indicated that weather conditions made them more fatigued at least some of the time. The most commonly reported fatiguing weather conditions were heat and/or humidity (70%) and rain (35%), but other conditions reported included wind (24%), cold (20%), overcast (11%), and snow or ice (11%). One respondent who indicated that ice was fatiguing noted that it was the strain of being on "high alert" due to traffic conditions that was so tiring. While specific weather conditions were commonly reported as sources of fatigue, only a few respondents said weather was a frequent source of fatigue, with most saying that weather rarely (64%) or never (23%) made them more tired.

Injuries and Near-Misses

About half (47%) of respondents reported that they had had an injury on a highway construction job at some time in their careers, and one-third of these missed at least one day of work due to the injury. None reported fatigue as a contributing factor; however, some reasons cited were suggestive (e.g., "miscommunication," "not paying attention," "just trying to get it done"). An even higher proportion of respondents reported a "near miss" (59%) at some point on a highway job, which the team defined for them as a situation that might have resulted in a serious injury if they had not acted in time. While all but one injury reported occurred on a day shift, more than half of near misses occurred at night (57%). In addition, six near misses were directly attributed to fatigue by the respondent. Near misses reported were primarily traffic-related (56%), including two police car chases and three incidents involving heavy equipment on site. In two instances, respondents at different projects reported that they mistook an active lane of traffic for a closed lane at night while struggling with fatigue.

Countermeasures and Attitudes

Napping was a reported countermeasure on highway construction sites; one in six respondents admitted to napping during breaks (Figure 3.8). Caffeine was used by nearly everyone, with half the sample drinking more than two caffeinated beverages per workday, and a quarter consuming more than three. Nearly two-thirds of respondents reported getting fatigue safety training, but when asked whether that training addressed adequate sleep, the proportion who reported training fell by one-third.

The attitude that fatigue could be overcome through force of will was expressed by nearly half of respondents overall (Figure 3.9). This attitude varied by occupational category, with professional and supervisory personnel being much less likely than labor to hold this attitude. Also, older workers were less likely than younger workers to hold this attitude. There was little variation in the belief that "fatigue is a safety problem," with 91% agreement. However, 44% of those who agreed that fatigue is a safety problem also agreed that fatigue could be muscled through.

Implications of Field Work Results

The team documented a general awareness of fatigue as a problem, especially for managers. Across the job sites the team visited, however, the team found little evidence of focused, systematic attention to the problem. The team were assured that fatigue training did take place, but this training appears

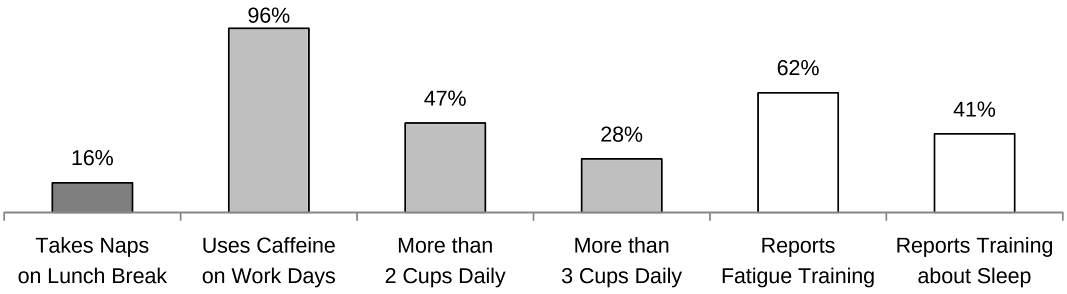


Figure 3.8. Individual fatigue countermeasures employed (n = 47).

to be largely informal, and may not focus on the importance of sleep.

With rapid renewal practices (e.g., weekend closures) workers reported excessive work hours. The nine respondents who worked the weekend closure reported about 73 h of work on average by the end of the Saturday, that is, by the end of Day 6 of what for most of them was a 12-day stretch. Individuals who worked the closure reported substantially higher levels of fatigue exposure as measured by both work schedule and sleep, as well as higher levels of sleepiness and critical sleepiness events. Findings from the team's natural experiment directly suggest a context-specific countermeasure: Personnel who work weekend closures should probably get Monday off.

The finding about critical sleepiness events is instructive; the questions were asked about sleepiness events (e.g., falling asleep at work, drowsiness while driving home) that occurred at any point during the respondent's current project, but respondents who had just come off of an extreme schedule were more likely to report such events than were others. This may simply be due to the question's greater salience for these respondents; more recent experiences are more likely to be recalled, which suggests that such sleepiness events may be underreported when stressors are farther in the past.

Respondents generally did not attribute injuries to fatigue, but their offered explanations may mask fatigue as a contributing factor. For near misses, fatigue combined with reduced visibility at night is clearly reflected in the traffic-related incidents reported.

Respondents reported using common countermeasures such as napping and caffeine. Napping is also likely to be underreported in this population due in part to widespread attitudes about fatigue, but also due to perceived or actual disapproval from peers and supervisors. Also, while employees reported receiving fatigue training, many managers interpret fatigue training as training related to heat exhaustion; relatively few survey respondents could recall safety training related to getting adequate sleep. High apparent agreement that fatigue is a safety problem may be due to respondents' desire to provide the acceptable response; however, it may also indicate a basic disconnect: Fatigue is a safety problem, but only if you can't muscle through it.

Finally, redundancy in supervisory staff, particularly managers and superintendents, is not highly valued. This lack of backup for key personnel directly contributes to both the long hours and high levels of fatigue widely reported anecdotally as being problematic among management in general.

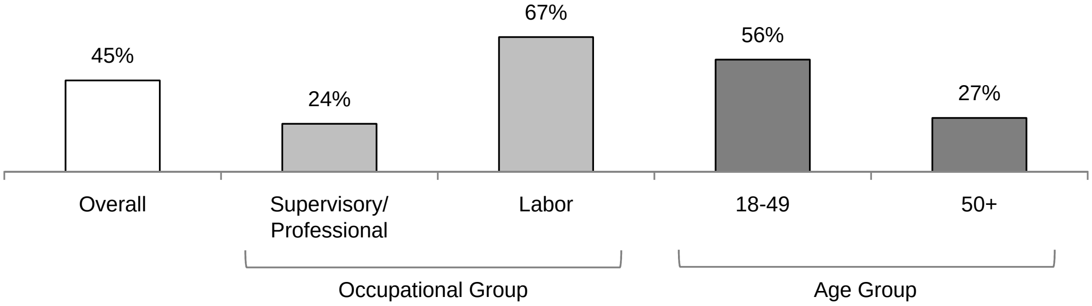


Figure 3.9. Agrees fatigue on the job can be "muscled through."

CHAPTER 4

Fatigue Countermeasures

A principal objective of the project was to identify promising fatigue countermeasures from the set of tools identified through literature review, for implementation in the rapid renewal environment through fatigue risk management plans and programs. Appendix C describes the detailed analysis of individual fatigue countermeasures identified and assessed in the review. This chapter integrates those findings in terms of the practical issues associated with deployment and implementation.

The review of literature concerning fatigue countermeasures identified 18 potential tools, which have been categorized as preventive or operational, as shown in Table 4.1. Preventive countermeasures are used to "maximize general alertness" and tend to be used in off-work settings. Operational countermeasures are employed in the actual work setting to mitigate the effects of acute fatigue. The countermeasures were reviewed in terms of the evidence supporting the impact on worker fatigue and performance, and in terms of their potential applicability in the highway construction environments the team observed during field work.

Factors considered included demonstrated impact on sleep and performance, the extent to which laboratory studies can be generalized and/or implemented in field settings, the existence of field studies, enhancement of worker knowledge, and the overall preponderance of evidence and clinical experience. There have been relatively few "pure" field studies of fatigue countermeasures in the traditional experimental design model. Instead, much material is based on laboratory studies of controlled sleep duration, simulated performance tests, and field studies of fatigue reports or error in shiftwork populations. Thus, countermeasure recommendations are usually a result of synthesis of clinical experience, observation of trends, abstract experimental studies, and model-based sleep/wake regulation and circadian rhythm principles. The result is a list of fatigue countermeasures categorized according to a general "effectiveness" metric, which combines the team's assessment of the strength of evidence concerning impact on fatigue and performance, the duration of that impact, and the likelihood of application and adoption in the highway construction environment. This latest aspect is essentially a judgment based on applied research and engineering knowledge and is meant to reflect the practical aspects of countermeasure application.

An additional classification for a number of countermeasures is "limited evidence or implementation complexities." The team uses this category for countermeasures that should work, in principle, but involve considerable technical complexity for implementation, have not been shown to impact fatigue or performance empirically, or entail medical supervision such as hypnotics and stimulants.

Among the 18 fatigue countermeasures identified, the team's evaluation suggests that nine of them have potential near-term applicability in the rapid renewal environment, comprising those tools in the "generally effective category." Additionally, the team believes two of the techniques in the "less effective" category warrant consideration for implementation: exercise and self- and peer-monitoring. Although exercise does not lead to prolonged fatigue reduction, it may serve to remove severely fatigued workers from the operational task and thus function as a rest break. Self- and peer-monitoring may not be as reliable an indicator as desirable, but it is unlikely to cause problems, and may identify potentially unsafe work practices.

Issues of Responsibility in Fatigue Risk Management

Fatigue risk management can be considered the responsibility of three levels or entities: (1) regulators, (2) industry/company, and (3) individual (Gander et al. 2011). Mature fatigue risk management programs rely on cooperative interaction between these levels, using appropriate communication, monitoring, and fatigue reduction tools.

Table 4.1. Fatigue Countermeasures Classified by Type and Judged Level of Effectiveness and Implementation Complexity

<table>
<tr><th rowspan="2">Impact</th><th colspan="2">Countermeasure Type</th></tr>
<tr><th>Preventive</th><th>Operational</th></tr>
<tr><td rowspan="2">**Generally Effective**</td><td>• Adequate Sleep
• Defensive Napping
• Good Sleep Environment
• Limiting Overtime and/or Work Schedule Modification</td><td>• Caffeine
• Napping
• Anchor Sleep
• Rest Breaks</td></tr>
<tr><td colspan="2">• Fatigue Education</td></tr>
<tr><td rowspan="2">**Less Effective**</td><td>• Diet</td><td>• Temperature and Ventilation
• Self- and Peer-Monitoring</td></tr>
<tr><td colspan="2">• Exercise</td></tr>
<tr><td>**Limited Evidence or Implementation Complexities**</td><td>• Hypnotics or Stimulants
• Model-Based Schedule Optimization
• Fatigue Risk Management System</td><td>• Worker Status Monitoring and Alerting Technologies
• Bright Light or Melatonin for Circadian Shifting</td></tr>
</table>

The Occupational Safety and Health Administration does not address work hours, with the exception of minors and overtime pay requirements. At the state level, companies operate under the requirements of state occupational safety and health agencies, which do not address issues related to working hours or fatigue. While a comprehensive review of state and federal requirements for fatigue management was not specifically required in this project, the team's selective review suggests that fatigue training and incident reporting is not mandatory, and the incident reporting protocols for state safety agencies do not collect information that pertains to work schedule, prior sleep–wake assessment, or other factors related to fatigue. State DOT contracting offices do not consider work scheduling in selection of proposals for award, and state-level inspection is focused on construction work quality; worker fatigue would need to be extremely egregious for inspectors to observe this and take corrective action.

At the level of industry and company, the team has found no information to suggest that fatigue is addressed in a systematic way across the highway construction sector. Searches of trade journals and industry association websites did not reveal anything to suggest that worker fatigue is considered a fundamental safety problem. Similarly, the guiding document for road construction zone safety practices, the *Manual on Uniform Traffic Control Devices* (FHWA 2009) does not contain any material addressing worker fatigue. Further, the results of the team's field data collection suggest that, at the company level, fatigue is considered as a general hazard of the job but not one addressed with systematic safety management processes. There is general concern about productivity of crews in relation to scheduling, but this appears to be more of an economic than a safety concern. SME interviews indicated that management considers being well rested and able to perform as an individual responsibility, within the parameters of work scheduling.

Individual responsibility for managing fatigue is an area that has not received much attention in the research literature. Review studies of demographics (Di Milia et al. 2011) have shown little in the way of systematic relationships between variables such as sex, age, job type, and so forth. Commuting distance has been shown to affect the amount of sleep people get. This may be an area of personal responsibility that could be addressed by contractors in assembling crews for specific jobs, by selecting people who live within a reasonable distance. More generally, the issue of personal responsibility for managing fatigue relies upon (1) knowledge of the worker about the factors contributing to fatigue and how to mitigate it, (2) the opportunity to obtain adequate sleep, and (3) taking advantage of the opportunity to obtain adequate sleep. Knowledge is an area that can be addressed through systematic education of workers; sleep opportunity can be addressed by schedule analysis and modifications as necessary. Actually taking advantage of the opportunity for adequate sleep is a complex lifestyle issue and depends upon workers being able to manage other aspects of their living patterns in order to prioritize the sleep opportunity and use it effectively. This would involve placing sleep at the top of the priority list among the many demands of the off-work period, such as family responsibilities, and the other activities of daily living such as food shopping and preparation, laundry, home maintenance, socializing, and so forth.

Levels of Defense in Fatigue Risk Management

In the research literature, conceptualization of fatigue risk management is based on multiple layers of defense. Gander et al. (2011) summarize the layers as follows:

- "Level 1 defence involves providing adequate opportunities for sleep, including recognising the importance of the placement of sleep opportunities with respect to the circadian cycle. This is the level partially addressed by traditional HOS regulations.
- "Level 2 involves processes for confirming that adequate sleep is obtained.
- "Level 3 involves processes to detect and prevent behavioural symptoms of fatigue.

Table 4.2. Levels of Defense in Fatigue Management and Applicable Near-Term Countermeasures

Level of Defense	Countermeasures	Current State of Implementation
Level 0–Education and Training	• Fatigue education program for highway construction contractors	• Training reported; content and quality not available for assessment
Level 1–Ensuring adequate sleep opportunity and proper placement within the circadian cycle	• Limiting overtime and/or work schedule modification	• Project labor agreements and superintendent heuristics • Job requirements may supersede usual practice (e.g., closures, need for work to task completion)
Level 2–Confirming that adequate sleep is obtained	• Obtaining adequate sleep • Good sleeping environment • Defensive napping • Anchor sleep	• No formal reporting or assessment • Variable level of knowledge among workers
Level 3–Processes to detect or prevent behavioral fatigue	• Napping • Caffeine • Rest breaks • Exercise • Self and peer observation	• Informal implementation of selected measures
Level 4–Processes for detecting fatigue-related errors	• Self and peer observation	• No data
Level 5–Processes for investigation of fatigue-related incidents and accidents	• N/A	• N/A

- "Level 4 involves processes for detecting fatigue-related errors.
- "Level 5 involves processes for investigation of fatigue-related incidents and accidents" (Gander et al. 2011).

Although many early hours-of-service rules were based more on operational experience and common sense than on research-based findings, the levels of defense classification scheme described here appears to assume that there is an adequate knowledge base of information concerning fatigue and circadian rhythm effects on worker performance. While this assumption may be correct in the highly regulated transportation industries because of the considerable research and development devoted to fatigue in these domains, it does not necessarily apply to the highway construction industry. Thus, the team proposes an enhancement to the Levels of Defense model to include the following:

- Level 0 involves fundamental education and training on sleep and fatigue effects upon work performance, the importance of adequate sleep to avoid these effects, and various other prevention and mitigation techniques (countermeasures).

For Level 2, confirming that adequate sleep has been obtained, Dawson and McCulloch (2005) focus on the use of PSWM on the basis of reported sleep obtained. Level 2 defenses are essentially treated as an organizational element to determine that the sleep opportunity provided by Level 1 defense is being acted upon appropriately. However, in considering the responsibility elements, it is reasonable to expand the definition of Level 2 to include individual checks on sleep obtained—basically information provided to the individual through training to ensure that fatigue countermeasures are properly applied.

The 11 countermeasures that the team judges to have near-term applicability in the highway construction environment are categorized within this taxonomy in Table 4.2.

Field Research Findings on Countermeasures

The team's field research results suggest some, but not all, of these measures are implemented in a somewhat informal manner in highway construction companies. For example, fatigue training was reported, although not illustrated, by about half the respondents. It is unclear, however, as to the specific content of this training. Similarly, for Level 1 defenses of ensuring an adequate sleep opportunity by limiting overtime or schedule modification, the team's field research indicates that project labor agreements tend to influence the maximum number of hours per day, in combination with superintendents' heuristics as to acceptable levels of productivity. Level 2 defenses of confirming that adequate sleep is obtained do not appear to be implemented. Management did not report using techniques such as prior sleep–wake assessment, and workers did not report strategies for ensuring the priority of sufficient sleep. Some Level 3 defenses are implemented on an individualized basis—for example, caffeine tends to be brought to the job sites by individual workers and rest breaks are taken as needed—primarily in relation to hydration. Napping is not generally sanctioned, and self or peer observation was not reported. Workers do report being able to get up and move around should they need to, which constitutes a form of exercise that may have a brief alerting function. Level 4 defenses involve detecting fatigue-related errors and are often associated with concepts of technological monitoring that are still in the research phase. Self- and peer-monitoring, however, can be used as a means to verify critical actions, and it has been suggested that this approach has contributed to the success of medical work-hour changes (Landrigan et al. 2004).

Detailed descriptions of the countermeasures listed in Table 4.2 are provided in Appendix C. Each of the countermeasures has an appropriate application and should be implemented in a systematic manner in order to ensure optimal benefits. The current approach of informal training and ad-hoc application of countermeasures may provide the appearance of attention to the fatigue problem without addressing it in a systematic and continuing way. The following section discusses the key issues associated with implementing more formalized approaches to fatigue management in the highway construction industry and suggests a path forward.

Implementation of Fatigue Countermeasures in Rapid Renewal Highway Construction

Motivations

The key challenge in implementing fatigue countermeasures in the highway construction industry is the lack of an economic framework that raises the issue to the level of a critical safety problem. Compounding this issue is the problem of a very wide range of organizations engaged in highway construction. They can range from relatively small companies to large joint ventures formed for the purpose of specific mega-projects.

Organizational safety culture is a related issue. Although the team has not conducted a detailed assessment of highway construction safety culture, the team is reasonably confident that most contractors working in highway construction may be thought of as having a "compliance culture." That is, the safety function is established at a level to address the most frequent and tangible safety elements, such as traffic incursions or slips and falls, without mechanisms to identify and mitigate various "latent" problems, such as fatigue related to weekend closures that could lead to accidents and injury either on the job or during the commute home.

The nature of the industry and the safety problems it engenders is another consideration. All of the industries associated with regulatory approaches to work-hour limitations tend to have substantial public safety aspects. For example, airline pilots are responsible for hundreds of lives aboard their aircraft; nuclear power plant operators are indirectly responsible for the safety of the public in wide geographic areas surrounding the plants they control; commercial truck drivers sometimes haul hazardous material and crashes of non-hazardous loads can injure or kill numerous others. Commercial ship crews are responsible for marine traffic safety and environmental integrity. Each of these industries is regulated at the federal level by work-hour limitations and many of the industries, particularly airlines, are leaders in the implementation of fatigue risk management systems.

The domestic and international political climate has shifted considerably over the past generation in such a way as to emphasize markets, privatization, and deregulation, in contrast with earlier periods of industrial regulation. In the United States, implementation or enhancement of work-hour limitations in selected industries is a countervailing trend and is advocated typically by safety and labor organizations, often in response to highly publicized events resulting in significant casualties or damage. Examples include the work-hour restrictions introduced by the Oil Pollution Act of 1990 in response to the Exxon Valdez crash and work-hour limits placed upon nuclear power plant operators by the Nuclear Regulatory Commission in relation to fitness-for-duty concerns.

Fatigue risk management systems are a potential alternative to prescriptive hours-of-service rules that would permit individual organizations more flexibility in conducting operations. This essentially involves adopting a risk-based approach to fatigue management that addresses work circumstances on a more individualized basis. It can permit organizations to analytically demonstrate to regulators either the rationale for exception to existing work-hour limits or to show regulators that existing work-hour limits are unnecessary in a currently unregulated industry. Fatigue risk management systems and modeling also are sometimes adopted by small subset innovator organizations to enhance worker safety (Dawson et al. 2011). It is this latter approach that is most likely to be effective in the highway construction industry, by focusing on companies and industry organizations that are trying to anticipate change and respond appropriately. As the team discusses in the following section, market analyses suggest that rapid renewal practices will increase over the next 10 years, and tens of thousands of workers and managers will be engaged in work that has increased risk for fatigue. The following section discusses a general approach for organizations to anticipate and respond to the likely problem of increasing fatigue risk factors in their business.

Risk-Based Approach to Fatigue Management and Fatigue-Proofing

The implementation of fatigue risk management will need to be carried out on an individual organizational basis, within the parameters of guidance established by a credible body. A number of such guidance documents exist today, one of the most comprehensive being that developed for Transport Canada civil aviation by McCulloch and colleagues (McCulloch et al. 2007; see http://www.tc.gc.ca/eng/civilaviation/standards/sms-frms-menu-634.htm). Much of this guidance material is quite detailed and of general applicability, although there is a substantial aviation component. The team's experience in the field research, however, suggests material of this type is unlikely to be accessed and adapted by individual contractor safety personnel. There is simply too much of it, and they do not have the training or experience to knowledgably modify the material to their specific circumstances.

Instead, the team foresees a need to (1) raise awareness of rapid renewal fatigue risk factors and potential consequences within the workforce, (2) develop simple risk assessment methods that can be applied to individual projects and work schedules, (3) provide contextualized fatigue training material to increase organizational and individual understanding of fatigue risk factors, countermeasures, and roles and responsibilities, (4) develop simple evaluation methods for assessing the application of countermeasures, and (5) identify potential methods to reduce the likelihood of fatigue-related error ("fatigue-proofing"). At this point, the team sees no utility in addressing project selection, since the team's field research indicated that work scheduling is not considered in the state DOT award process, and attempting to implement this approach would encroach upon the safety responsibilities of state occupational safety and health agencies.

The main phases of implementation of fatigue risk management in the rapid renewal highway construction industry are as follows:

- Awareness of risk factors and motivation to mitigate them.
- Assessment of risk factors for specific project operations.
- Development and implementation of fatigue training for workers and managers.
- Development of methods for monitoring and assessing risk factors and countermeasures, and
- Identification of fatigue-proofing strategies for specific operations.

Each of these elements is discussed in the following sections.

Fatigue Risk Awareness

Fatigue risk awareness appears to be present in the stakeholders the team has surveyed, although it does not appear to be particularly salient as a worker safety issue. Thus, an initial phase of fatigue risk management implementation is to ensure the problem is properly understood as an enhanced risk associated with rapid renewal construction practices—an issue that goes beyond those typically encountered by shift workers. Risk awareness is a process that needs to be undertaken at the industry sector level, within state DOTs, and with individual contractors. The team believes that a key element of this process is an appropriate dissemination pathway, a means of providing information to stakeholders through a recognized and respected authority within the construction industry. This will help to establish credibility.

Fatigue risk awareness can be raised through a variety of dissemination pathways, including the American Association of State and Highway Transportation Officials, the National Cooperative Highway Research Program, and the Association of General Contractors. Each of these organizations holds meetings at national, regional, and local levels that would be appropriate for presenting fatigue awareness briefings. Additionally, outreach material provided through the organizations to constituent members would facilitate awareness. A critical issue for this process is identifying the most appropriate dissemination pathway(s), and then defining outreach material based on current communication approaches. Fletcher et al. (2005) review approaches to driver fatigue awareness campaigns and suggest fatigue should have parity with other safety concerns, such as drinking and driving, speeding, and so on. A similar approach could be taken in the highway construction industry.

Project-Specific Fatigue Risk Scenarios

Since highway construction is project-based and episodic, that is, there are different activities scheduled for different times, it is important to develop a range of scenarios for worker scheduling based upon the major risk factors. This is likely to incorporate variants of the major risk factors, such as 55-h closures, extended shifts, and others. Operational exigencies dictate the need for these types of schedules, and general guidance may be of limited use in any particular set of circumstances. Therefore, it is appropriate to develop a set of articulated risk scenarios corresponding to some of the most common situations that contractors may have to address on an ad-hoc basis. This might include the unexpected need for double shifts, shifting to night shifts with no intervening day off, extended numbers of sequential days following a closure, overseeing closure work by salaried personnel not subject to hourly labor agreements, and so forth. Fatigue risk analysis via PSWM and countermeasure alternatives can be used to characterize these scenarios and is illustrated in the following chapter.

Contextualized Training for Workers and Managers

An understanding of the fundamental nature of sleep loss, circadian rhythm, fatigue, performance impacts, and amelioration strategies is a key element of both preventive and operational approaches to reducing fatigue. Education and training formed the basis of the highly successful NASA fatigue countermeasures program and over time led to a fundamental change in culture and philosophy regarding fatigue, both at the worker and management level. Education is a basic element of current approaches to fatigue risk management systems and can help to overcome widely held misconceptions about the nature of the problem and ways to deal with it.

While important as a fundamental component in fatigue management, translation of existing scientific knowledge into usable programs for employers and workers is not straightforward. The interviews with management SMEs suggested that fatigue is a topic of concern, and that there is some coverage of the topic in company safety training. The results of the interviews, however, yielded no material that would allow for assessing the quantity or quality of the training. The single source the team reviewed, "toolbox talks," yielded some relatively cursory material that was not contextualized to the rapid renewal environment.

Educational programs could be imported and adapted from transportation industries such as commercial aviation. Comprehensive and contextualized training about fatigue for the rapid renewal environment will need to address the risk factors and operational constraints specific to this work domain. These include long shifts, occasional double shifts, rapid switch to night work from day work, and continuous weekend closure effects upon sleep opportunity. Now there are no standards to guide contractors in their selection of consultants or material for fatigue training, nor is there a well-developed information dissemination pathway. This may be an appropriate role for industry association groups, which have established training material and guidance for other areas of safety concern.

Assessment Methods and Metrics

A legitimate question concerning any new technique implemented in organizations is "how can we tell if it is working?" An ideal evaluation would involve longitudinal data collection from groups working identical projects and schedules, with and without fatigue management techniques. Data for such an evaluation would range from knowledge comprehension to measured sleep obtained and safety impacts on the job. Practically, however, this will not happen in the rapid renewal construction environment, and so evaluation should probably be aimed at building confidence in the utility of the fatigue risk management approaches through other means. This might include informally surveying personnel about their knowledge of fatigue fundamentals, how well certain countermeasures work for them, and their ideas for program enhancement.

Specific tests of knowledge related to training programs can be developed, based on material already available, such as that for Transport Canada. Care must be taken, however, not to portray the assessments as potentially punitive, and reactions regarding questions of sleep obtained need to be monitored for concerns related to privacy.

Fatigue-Proofing Strategies

Most of the discussion of fatigue tends to focus on fatigue reduction through interventions that provide greater opportunities for recovery sleep. Safety management systems theory and practical experience, however, indicate such controls will not always be effective. Either because of project work requirements or schedule risks that are considered acceptable, there will be situations in which fatigued workers are at work (Dawson et al. 2012). In these situations, risk reduction is handled by "reducing the likelihood that a fatigue-related error will cause an accident or injury" (Dawson et al. 2012). This approach is referred to as "fatigue-proofing" and can be considered an approach to fail-safe operation.

Dawson et al. (2012) suggest that fatigue-proofing techniques are in common use, but tend to be hidden as "implicit elements of the safety system" that have evolved with work practices. They illustrate a number of examples from the maritime, aviation, health care, and power industries that involve approaches such as verbal call-backs of commands, additional preparation for critical operations, repetition and confirmation of instruction, and use of higher levels of team jocularity during early morning work. In this latest example, individuals who are more irritable or unresponsive tend to be fatigued and are assigned lower-risk tasks.

The common themes in these examples are the pre-signaling of higher risk and a higher level of scrutiny for potential error. This is communicated to other individuals, so the result is greater team situational awareness and error scrutiny. Identification and development of these types of strategies during extended work periods for highway construction is warranted, since fatigue reduction by means of schedule adjustments may not always be feasible.

CHAPTER 5

Critical Issues for Fatigue Risk Management in the Highway Construction Industry

The information collected and analyzed in the team's field research and reviews of fatigue research from other work domains needs to be viewed in the context of the highway construction industry. This industry has a set of established practices and operational constraints that will influence how fatigue risk management is carried out. This chapter discusses what the team views as critical issues and risks associated with implementing fatigue risk management in this industry.

Critical Issues and Risks

Fatigue Is a Safety Issue not "Owned" by a Specific Stakeholder

Occupational and public safety related to fatigue resulting from work schedules generally falls under the purview of a regulatory agency that oversees the industry of concern. This is true for aviation, maritime commerce, interstate trucking, railroads, and nuclear power plants. All of these industries are overseen by specific regulatory agencies, and each industry must comply with a set of work-hour rules that are designed to reduce fatigue problems among personnel. Individual organizations in each of these industries are responsible for complying with the work-hour limits, or demonstrating that exceptions do not increase risk. Although the work-hour rules are not a panacea for fatigue problems, they have motivated considerable research and innovation among affected industries to implement fatigue management programs. Additionally, in most of these industries, there have been high-profile incidents or accidents that can be directly linked to work performed at times when fatigue is highly likely (e.g., early morning hours), and in several industries there are active union committees charged with ensuring sufficient rest for their members.

Highway construction contractors are distinct from the individual operating entities in the industries mentioned above in that their safety performance is not the purview of an independent federal regulatory agency. OSHA establishes broad operating parameters for rest breaks and overtime pay, and more detailed safety oversight occurs at the state level. OSHA and state safety agencies simply require injury or accident reporting to be documented; they do not investigate for root causes such as fatigue.

Fatigue thus falls into an "institutional no-man's land," with insufficient motivation in any organization to systematically address the issue. Contractors currently handle worker fatigue in two ways: (1) generally limiting work to 55-h weeks, with the exception of closure periods, and (2) implementing informal countermeasures such as caffeine and rest breaks as necessary. Neither approach represents a systematic means of fatigue reduction; the pressures of job performance seem to outweigh concern with adequacy of worker sleep.

The primary risk related to this issue is that the problem will continue to be acknowledged as a work-related risk, but one that does not warrant attention at a level sufficient to address it properly. The field research data suggest that the problem is indeed recognized, yet there are inconsistent attitudes regarding training received and the general need to "tough it out." The team was also told explicitly by one contractor that "when it matters to OSHA, it matters to us."

Fatigue Risk Management Programs May Be Over-Sophisticated for the Current State of the Industry

Given the lack of external or internal motivators described in the previous section, and the team's field observations of construction contracting companies, the team is concerned that the concept and particulars implied by "fatigue risk management systems" (FRMS) may be overly complex for most construction companies. The few published analyses of FRMS implementation portray industries of the type described above: regulated operations, usually within the transport sector (Fourie et al. 2010; Gander et al. 2011). It is likely that the safety functions in regulated industries are more developed than in construction companies. The largest project the team investigated is a $350 million, 3-year program, based on a joint venture between two large companies; this project was served by one full-time safety officer. In smaller firms or projects, the safety function appeared to be served by a foreman on a very part-time basis. The team's field research did not penetrate the "upstream" portion of the organizations, which may have more extensive safety staff than the team observed. Given these fairly minimal staffing levels (and that available resources are probably small) it would be a considerable challenge to implement FRMS in the manner typically described in the literature. Implementation of FRMS implies a high degree of organizational development into which specific policies and practices concerning fatigue mitigation would be introduced.

Available data from process evaluations (Fourie et al. 2010) suggest that even the regulated transport organizations have some difficulty implementing FRMS, due to resource limitations, unclear guidance from the regulator, and a tendency to "cut and paste" regulatory guidance templates into a policy document and feed it back to the regulator. Other observations include uneven implementation across organizations, a tendency of smaller operators to lack resources or interest, unfamiliarity or discomfort with fatigue modeling software, increased administrative workload, conflict with organized labor, and inconsistent application.

The principal risk in developing FRMS implementation guidance is that it would simply go beyond the capabilities of most contracting firms. The team believes that FRMS as currently conceived in the literature, coupled with low motivation and lack of belief in the economic impact of fatigue, will be too complex for most firms to undertake. This problem also applies to specific aspects of risk management tool development and project selection. The team's field research suggests that fatigue and work scheduling currently play no role in risk assessment and contract award selection, and that attempting to introduce such approaches without a "push" from project oversight agencies, or at least a clear business value proposition, will be problematic.

Safety Data Are Extremely Limited

In the literature review the team discussed the limitations of data concerning the linkage of safety problems on the job to fatigue and scheduling parameters. This is the case in the highway construction sector, but also more generally. The estimated range of fatigue-related safety problems is quite wide—from 4% to 33%, using data from various transportation sectors (Gander et al. 2011; Horne and Reyner 1995; McCallum et al. 1996). It is reasonable to assume that the same range is applicable in the highway construction sector. The lack of data concerning accidents and injuries in highway construction in relation to fatigue and scheduling, however, is another factor contributing to reduced motivation to address the problem. Since state agencies do not require collection of prior sleep-wake history in accident reports, there is no database being developed to help understand the problem. This problem is inherent in most accident investigation procedures. Unless prior sleep-wake data are collected as a routine matter in accident investigation protocols, only the most severe accidents where fatigue is already suspected will address worker sleep history.

As described in the fatigue countermeasures review, data are limited regarding the effectiveness of interventions such as training and more sophisticated fatigue risk management systems. Without demonstrated causal relationships between fatigue and accident and injury risk in the highway construction sector, as well as solutions that have been shown to reduce the problem, operators are likely to conclude that they are doing the best they can and are operating with acceptable risk.

A Credible Dissemination Pathway for Fatigue Risk Management Tools Is Needed

Development of various products, such as fatigue training and countermeasure tools, assumes effective ways to distribute the material. The most important issue to be addressed concerns the mechanisms and responsibilities for an online repository, that is, a website that is routinely maintained and can provide access to the various materials. Experience, however, has shown that a website is insufficient for widespread outreach. In addition, the website needs to be made broadly available through other sources that are routinely contacted by highway construction safety personnel. Principal organizations in this regard would be the American Association of State and Highway Transportation Officials (AASHTO), the American Road and Transportation Builders Association (ARTBA), the Associated General Contractors of America (AGC), and possibly the OSHA/FHWA Work Zone Safety website.

Rapid Renewal Market Growth, Fatigue Safety Impacts, and Training Needs

Overview

This section discusses the potential size of the rapid renewal highway construction market and the corresponding workforce needs over the next 10 years, and it evaluates the impact this renewal effort will have on the overall workforce, including potential worker training needs and potential impacts on safety. The basis for this analysis was data contained in several sources, including the FHWA *Conditions and Performance* report to Congress (e.g., U.S. DOT 2008), the Bureau of Labor Statistics (BLS), and state-level data concerning specific historical lane mile construction for different pavement types in order to estimate labor requirements for rapid renewal projects.

The team's general finding was that there is considerable uncertainty in making these types of forecasts, because of changes in economic outlook and the level of granularity available in the data. For highway construction, budgets at the federal and state levels, for example, tend to be categorized very broadly in terms of new construction, maintenance, and rehabilitation. Rapid renewal projects fall within the latest category, but there is no information provided within budgets that allows determination of the rapid renewal component. Similarly, the data concerning safety impacts in highway construction are very sparse, thus restricting the team's ability to estimate the fatigue-related component of safety impacts in rapid renewal.

Notwithstanding these limitations, this section describes an analytic process and its application to data that the team deems to be representative program estimates for rapid renewal construction.

Rapid Renewal Program Size Estimates

Throughout the United States, governments spent $161.1 billion on highways in 2006. About $78.7 billion (48.8%) of this total was spent on capital projects. Of the $78.7 billion of capital spending in 2006, $40.4 billion was spent for rehabilitating the existing system; $16.2 billion was used to construct new roads and bridges; $13.8 billion was used for widening existing facilities; and $8.2 billion supported system enhancements such as safety, operational, and environmental enhancements. The portion of total capital outlay funded by the federal government rose from 41.6 to 44.0% between 1997 and 2006; while state and local capital investment increased from $28.3 billion to $44.1 billion. These and related outlays and percentages are illustrated in Table 5.1 (U.S. DOT 2008).

Table 5.1. Highway Expenditures in the U.S. by Category in 2006

Activity	Amount (B$)	Percentage
Rehabilitation (renewal)	40.4	25.1%
New roads and bridges	16.2	10.1%
Widening existing facility	13.8	8.6%
Support system enhancements	8.2	5.1%
Maintenance & operations	40.4	25.1%
Safety	14.5	9.0%
Administration costs	13.2	8.2%
Interest and bond retirement	14.2	8.8%
Sum	160.9	100.0%

Table 5.2. Budget Figures for Highway Construction in California, 2006 (Caltrans 2008)

Expenditure	Amount	Lane Miles
Capital Preventive Maintenance	$229 M	1,358
Preventive Maintenance	$43 M	957
Base Maintenance	$28 M	381
Rehabilitation	$367 M	654

A contrasting profile is illustrated by data from California, which shows that rehabilitation work in the 2006 time period comprised more than 50% of the highway construction work, as shown in Table 5.2. This table also lists an important parameter in estimating workforce requirements, namely, the number of lane miles to be rehabilitated.

Historical data concerning lane mile construction trends are difficult to obtain. The team reviewed data sources from three states, including California, Texas and Washington, and concludes that Washington state (1) provides the most useful sources of historical construction data in terms of lane miles per year and (2) is more likely "average" in terms of its road network than larger states such as California and Texas.

Workforce Estimates

The BLS maintains data on current and projected employment in a variety of sectors. This information is available for the specific sector of highway construction. The team's SME in highway construction engineering developed a comprehensive list of job classifications for typical projects and used this as a basis for accessing the BLS tool for projecting workforces in specific industrial sectors. The BLS tool projections "are developed in a series of six interrelated steps, each of which is based on a different procedure or model and related assumptions: labor force, aggregate economy, final demand (GDP) by consuming sector and product, industry output, employment by industry, and employment by occupation. The results produced by each step are key inputs to following steps, and the sequence may be repeated multiple times to allow feedback and to insure consistency" (BLS 2012).

Table 5.3 provides the output of the BLS tool for the key occupations involved in highway construction. It shows the overall anticipated increase in employment in the 10-year period between 2008 and 2018 is 16%.

In order to determine the extent of this workforce that may be involved in rapid renewal construction, the team modeled the work requirements of specific types of lane mile construction—rigid and flexible using the Construction Analysis for Pavement Rehabilitation Strategies program

Table 5.3. Estimated Workforce in Highway Construction Jobs, 2008–2018

Occupation	2008		2018		Change	
	Employment (in thousands)	Percent of Industry	Employment (in thousands)	Percent of Industry	Number (in thousands)	Percent
Total, all occupations	328.9	100.00	380.4	100.00	51.5	15.7
Construction laborers	83	25.25	104.9	27.57	21.8	26.3
Operating engineers and other construction equipment operators	47.2	14.35	52.9	13.91	5.7	12.1
Paving, surfacing, and tamping equipment operators	17.8	5.41	19.9	5.24	2.1	12.0
Cement masons and concrete finishers	12.8	3.88	14	3.68	1.2	9.8
Construction managers	7.6	2.33	9.4	2.47	1.7	22.6
Excavating and loading machine and dragline operators	3.9	1.18	4.5	1.18	0.6	15.7
Highway maintenance workers	2.6	0.78	2.9	0.78	0.4	14.8
Maintenance and repair workers, general	2.3	0.70	2.7	0.70	0.4	15.7
Reinforcing iron and rebar workers	1.8	0.53	2	0.52	0.2	12.2
Mixing and blending machine setters, operators, and tenders	0.3	0.09	0.4	0.10	0.1	34.6
Construction and building inspectors	0.3	0.08	0.3	0.08	0	10.2
Crushing, grinding, and polishing machine setters, operators, and tenders	0.1	0.04	0.1	0.04	0	12.3

Source: BLS, n.d.

(CA4PRS; http://www.fhwa.dot.gov/research/deployment/ca4prs.cfm). CA4PRS, FHWA's market-ready technology product, incorporates three interactive analytical modules: a Schedule module that estimates project duration, a Traffic module that quantifies the delay impact of work zone lane closures, and a Cost module that compares project cost among alternatives. Typically, highway pavement renewal projects consist of the following major activities during construction:

- Pavement demolition activities: milling, saw cut, excavation, loading, and hauling to dumping yards.
- Paving activities: material delivery and supply from plants, base paving, asphalt paving, concrete (including precast) paving, compaction, cooling, curing, and finishing.
- General activities: traffic control, lane marking, quality control, lighting, clean up, and field management.

First, construction productivity (in terms of lane mile per closure) of typical pavement renewals is estimated, using CA4PRS schedule analysis. Based on the productivity, the total size of human resource (contractor crew and agency staff) in terms of their numbers and duration is calculated. CA4PRS schedule analysis output indicates the configuration of typical major equipment resources, such as hauling and delivery trucks, paving machine, and production plants with their usage (operations) hours per closure. Contractors' crew such as equipment operators and laborers are derived from these major equipment operation activities outputs.

The team applied CA4PRS analysis to the anticipated pavement renewal expected in Washington state for the next 10 years to provide a baseline for scaling up to the United States. The following assumptions were incorporated:

- There are 110 working days per year on average (May to October).
- Rapid renewal will be approximately 40% of the total renewal market.
- Washington state total renewal over 10 years will be 8,580 lane miles.

Using these inputs, CA4PRS calculates that the rapid renewal contractor workforce will require approximately 500 workers per year. Scaled up to the United States this workforce would currently entail 25,000 workers; with the 16% growth expected in highway construction employment by the year 2018, this workforce would require 29,000 workers.

Training Needs

As indicated in the preceding section, the team estimates that 25,000 to 29,000 highway construction personnel will be engaged in rapid renewal work at some point over the next 10 years, and thus that is the number of workers that the team estimates could benefit from fatigue-oriented training. The working group members who have responded to the project's request for comments suggest these estimates may be low, given the increasing backlog of maintenance work to be done. This needs to be balanced against the prospect of continuing economic problems and their adverse effect on highway construction.

Notwithstanding these factors, the training needs for this workforce are readily apparent on the basis of the team's field work and assessment of the current state of fatigue countermeasure implementation. The basic content of fundamental training should be the same for labor and management and includes the following content areas:

- In the long run, there is no substitute for sleep.
- Fatigue is based on physiological mechanisms and cannot be overcome by motivation or willpower.
- Self-assessment can be unreliable and potentially biased by work circumstances, but can be useful with attention to specific circumstances.
- Individuals vary in sleep need and responses to sleep loss, and it is difficult to predict on a case-by-case basis.
- There is no "one-size-fits-all" solution.
- There are ways to prevent and mitigate fatigue, but they must be properly employed.
- Fatigue has safety, well-being, and economic consequences.

Additional content areas that might be stressed for managers would include the following:

- Managers are not immune to fatigue and should not use the mantle of responsibility to ignore basic sleep needs.
- Rapid renewal schedule work practices have differential effects upon fatigue and can be cumulative.
- Specific rapid renewal manifestations, such as lack of a day off when switching to night shifts or many continuous days of work following a closure, need to be addressed with specific countermeasures.
- Fatigue-proofing strategies can be developed and employed when project requirements preclude fatigue-reducing schedules.

These later two points emphasize the importance of developing countermeasures and interventions that are specific to rapid renewal work. Additionally, the fundamental training material will need to be contextualized to the highway construction environment by providing appropriate illustrative and operationally relevant examples. Although the team had initially considered developing training content that would be specific to state DOT officials, the field work suggests that they are subject to many of the same fatigue risk factors as contractors and can benefit from similar training content.

The original NASA fatigue countermeasures training took several days at the NASA-Ames field site and was presented by experts in fatigue research. Over time, the material from that program has been disseminated widely and adopted by numerous operational organizations—primarily airlines. More recent material of a similar nature has been developed for Transport Canada and contains an emphasis on fatigue risk assessment at the individual level by PSWM. These prior efforts tend to generate material that is made publicly available, with the expectation that it will be accessed and adapted by users with training needs.

The team's impressions of the highway construction industry suggests that "turn-key" material is most likely to be used, and it should not be expected that individual contractor safety officers will adapt material from publicly available documents. This latter approach has been attempted, and the quality and utility of the resulting adaptations is unclear. The team's assumption is that safety officers confronted with detailed web-based documents would most likely abandon the effort to develop training material, or down-select material in such a way as to reduce effectiveness.

Safety Impacts

Numerous studies have demonstrated that impaired neurobehavioral performance and elevated risks for injuries and accidents are associated with extended schedules and shift work in manufacturing (Folkard and Tucker 2003; Folkard and Åkerstedt 2004; Folkard and Lombardi 2006; Folkard et al. 2006), transportation (Hursch et al. 2006), and medicine (Landrigan et al. 2004; Ayas et al. 2006; Barger et al. 2005; Gander et al. 2008; Sharpe et al. 2010). The U.S. construction industry is among the most hazardous for workers. In spite of the prominence of construction in occupational injury and death, however, few studies have evaluated the contribution of schedule or fatigue to this very high risk among these workers, and none evaluates these risk factors among highway construction workers; studies of accidents among highway construction workers focus instead on immediate causes (Pegula 2004; Mohan and Zech 2005; Center for Construction Research and Training 2008). Below is a standard risk assessment model used in public health research to guide the estimation of the numbers of persons at risk for any health- or safety-related outcome:

$$M = P \times B \times DR \times E$$

where

- M is the number of deaths (or injuries, etc.) attributable to a cause;
- P is the population at risk (in this case, the number of highway construction workers);
- B is the baseline mortality rate (or injury rate, etc.);
- DR is the dose response (i.e., the size of the effect of increased exposure on the outcome); and
- E is the level of exposure to the causal factor.

If all required data elements were available, this model could be used to estimate the numbers of accidents or injuries (M) that could be expected based on different work schedules, such as schedules commonly used in rapid renewal highway construction relative to those used in more traditional highway construction. The main presumption in this analysis would be that fatigue is the intervening factor between work schedule and the increased accident or injury rates.

The field research provides some evidence that work schedule affects fatigue levels in highway construction workers; however, it cannot provide the data elements necessary to perform the estimation above, primarily due to limits of sample size and study scope. Analyses of risk factors in accidents typically require very large samples and the less frequent the accident, the larger the sample required. In addition, to link accidents reliably with schedule-related factors would require reports to be collected as soon as possible after the accidents, and these reports would need to include detailed information on recent work and sleep schedules.

At best, three of the necessary data elements are available in the public domain, and all have significant limitations. First, the population of highway construction workers (P) is estimated by the BLS, which also provides projections of this population over the next 10 years. Estimates by occupational category within highway construction are also provided. But BLS figures do not provide a breakdown by type of activity, such as new construction versus renewal. Here, the team uses estimates of the rapid renewal workforce described above. These estimates have their own limitations, including extrapolation from operations in a single state to represent operations throughout the country. However, this approach has the potential for estimating workforce needs by occupational group or task, so that specific fatigue profiles could be applied, if known.

Second, the literature on construction worker accidents related to schedule provides statistics for some schedule characteristics analogous to the dose response (DR) element required, at least for occupational injuries. Two studies using the same national survey dataset (the National Longitudinal Survey of Youth) found links between workplace injuries and work schedule among construction workers. In the first, those working more than 8 h per day (odds ratio = 1.02, $p < .01$), more than 50 h per week (OR 1.98, $p = .03$), or starting work before 7:00 a.m. (OR 1.28, $p < .01$) were all found to be more likely than others to report a work-related injury when adjusting for other risk factors (Dong 2005). Significant findings from the second study also included a positive association between overtime work and likelihood of injury relative to not working overtime (hazard ratio 1.48, $p < .05$), as well as increased risk of injury related to working the evening shift compared with day shift (hazard ratio 2.86, $p < .05$), after adjustment for other risk factors (Dembe et al. 2008). A hazard ratio is the ratio of two hazard rates and is similar to a relative risk. A few other studies suggest relationships between schedule or fatigue and injuries (Lowery et al. 1998; Arditi et al. 2007; Powell and Copping 2010); however, effects appropriate for risk assessment based on specific schedules are typically not reported.

Assuming that effects reported for construction workers generally are adequate proxies for highway construction workers specifically, statistics derived in these studies could be used to estimate numbers of injuries based on working more than 50 h a week compared with working less; starting work before 7:00 a.m. compared with starting work later; working overtime hours compared with no overtime; and working evening shift compared with working day shift. The data source used to derive these estimates is publicly available and could be used to make other comparisons based on a number of relatively simple schedule differences. To the extent that these comparisons "look like" the differences between rapid renewal scheduling practices and traditional scheduling practices, the dose response estimates may be useful. However, there are additional limitations to these particular survey-based estimates. The data source relies on self-reporting of hours worked and injuries, and it requires the respondent to recall details over a relatively long period of time. Also, work schedules may be highly variable over time, and information about the schedule being worked at the time of the injury may not be available. Finally, these studies can consider only injuries, not fatalities or other incidents of potential interest (e.g., near misses).

Third, the same data source that provides limited dose response values can be used to estimate a baseline injury rate (B), that is, the rate of occupational injuries that occur with "traditional" schedules. In order to calculate either the number or the rate of injuries attributable to rapid renewal scheduling scenarios, the team must first know the portion of the total rate that occurs under the traditional schedule scenario. For example, in one study, 10.4% of construction workers working 7 to 8 h per day reported a work-related injury in the prior year (Dong 2005); this figure could be considered the baseline injury rate. However, all the same limitations apply here as apply to the dose response estimates derived from the same source.

The baseline rates for injuries, fatalities, or other incidents are not available from other national sources. Injury and fatality rates reported by the BLS, by OSHA, and others are overall rates, and sufficient information to decompose these rates into partial rates by any work schedule element (e.g., nights versus days, overtime versus non-overtime) is not available. Even the detailed accident reports generated by occupational fatalities do not usually mention things like work schedule or sleep obtained. One state DOT SME respondent when asked why he thought such details were not made part of the official record in either individual reports or in official statistics answered that there was "no interest" in doing so. Some sources provide estimates for the proportion of injuries due to fatigue (Gander et al. 2011; Horne and Reyner 1995; McCallum et al. 1996); however, such estimates are not useful as elements of the risk assessment model because the estimates, as typically reported, do not offer the degree of granularity required to differentiate the fatigue component in different groups, and may have little relevance outside the domain of origin due to substantial differences in work schedules and task requirements.

The final element, level of exposure to the causal factor (*E*), is not available. In this case, exposure would be operationalized as the proportion of workers exposed to an "at-risk" schedule (i.e., a schedule used more frequently on rapid renewal projects, such as night and extended shifts) and for how long. The estimate of 25,000 to 29,000 highway construction personnel in rapid renewal, about 40% of the overall highway workforce, is not adequate for estimating level of exposure to risky schedules. There is wide variability in schedules in both rapid renewal and traditional projects; extended schedules and night work may be used in both but to varying degrees, and even in rapid renewal environments some scheduling practices (e.g., nights) are not used consistently. A comprehensive approach would evaluate, first, the relative risks associated with exposure to different schedules, and second, the relative risks associated with the perhaps increased propensity to use higher-risk schedules over lower-risk schedules on rapid renewal projects. No extant data source provides this information.

Elements like exposure, and perhaps the baseline rate and dose response, may be most reliably estimated when data can be obtained directly from sources such as contractor and DOT payroll records and accident reporting mechanisms. Significant bureaucratic obstacles exist, however, in acquiring these kinds of data. Additionally, even if these data were made available from among the projects recruited for the study, there would remain significant methodological challenges to ensuring that the data obtained were sufficiently representative to yield estimates that could be generalized to a larger population. While the team is reasonably confident that ours and others' findings support the claim that increasing use of rapid renewal practices is likely to result in both higher rates and larger numbers of occupational injuries, it is not possible at this time to quantify these effects with precision.

Although a formal risk assessment of the impact of fatigue on occupational safety for highway construction workers cannot be made, the team can make rough, preliminary estimates of the number of fatigue-related injuries in the rapid renewal workforce using two approaches.

The first approach combines injury and fatality statistics for the construction industry published annually by the BLS (here, treated as the baseline rate) with published estimates for the proportion of accidents due to fatigue (here, treated as the dose response) and estimates of the size of the rapid renewal workforce (the population), with the assumption that exposure is uniform for all members of the rapid renewal workforce. The BLS reported 4.3 nonfatal injuries per 100 full time equivalents (FTEs) in 2009 within the construction industry as a whole [North American Industry Classification System (NAICS) code 23], and 4.6 per 100 FTEs in highway, street, and bridge construction specifically (NAICS 2373) in the same period (BLS, 2010). Estimates for the rate of fatigue-related accidents vary widely, from 4% to 33% (Gander et al. 2011; Horne and Reyner 1995; McCallum et al. 1996); the midpoint of this range is approximately 20%. Applying the midpoint of the fatigue estimate range (20%) to the highway construction injury rate (.046) and the expected number of FTEs based on the projected personnel in rapid renewal highway construction over a 10-year period (see above), the team estimates at least 230 to 267 nonfatal injuries per year due to fatigue on rapid renewal projects. In the construction industry overall, 9.9 fatalities per 100,000 FTEs were reported in 2009 (BLS 2010). When the same procedure is applied to this rate, the team estimates about one-half a death per year in the rapid renewal workforce. The limitations to this approach are clear. The baseline rates used are not true baseline rates because they correspond to the population as a whole, not just to those working "traditional," lower-risk schedules. Also, the dose response used is not specific to any activity or schedule, and exposure to high-risk versus low-risk schedules is treated as uniform within the rapid renewal workforce.

A second approach combines the same population estimates as above with estimates for construction workers overall reported by Dong (2005). This study estimated an unadjusted incidence of an occupational injury among workers who reported working more than 8 h per day of 15.0%, compared to only 10.4% (the baseline) among those working a 7-h or an 8-h day. The proportion of the incidence attributable to the longer work shift (analogous to the dose response) is $15.0\% - 10.4\% = 4.6\%$. If the projected rapid renewal workforce estimate is treated as the number of individual workers, then between 1,150 ($.046 * 25{,}000$) and 1,334 ($.046 * 29{,}000$) workers each year in the rapid renewal workforce would be expected to sustain an injury attributable to fatigue as a result of their longer schedules. The number of expected injured due to fatigue is much higher using this approach. A complication with this method is that the incidence rates reported in Dong are based on individual workers rather than FTEs and are therefore not adjusted for exposure. If respondents who worked longer hours have a higher incidence rate than those working shorter hours, this higher rate is partially explained by their increased exposure to the risk injury. This method also requires use of the same problematic uniformity-of-exposure assumption as the first approach.

In conclusion, only very tenuous estimates of the safety impact of work schedule and fatigue can be made at this time; the above estimates are simulations only, requiring major assumptions. Data with more granularity are required to make progress on this front, and these data are not likely to become available soon.

CHAPTER 6

Organizational Approach to Fatigue Risk Management in Rapid Renewal Highway Construction

An integrated approach to fatigue risk management for highway construction work needs to accommodate the unique characteristics of the environment, including the general industry approach to safety, the seasonal nature of construction work, and the likelihood of unpredictable schedule changes due to various factors such as weather, unforeseen obstacles, re-work, and so forth. This chapter discusses an overall organizational approach to fatigue risk management, including processes and implementation steps for organizational practices that are generally applicable across contractors of various sizes, and work schedule and work practice guidance based on fatigue modeling of schedules typically encountered in rapid renewal construction. Fatigue management is a joint responsibility between management and individual employees; this section establishes processes to implement the collaborative approach.

Organizational Practices Guidance

This section describes adaptations of organizational practices for fatigue risk management that are appropriate for a self-regulated industry such as highway construction, with a focus on monitoring and mitigation. The approaches described in this section are meant to be flexible and adaptive, so that they can apply to a broad range of organizational size and complexity.

Figure 6.1 illustrates the elements of organizational practice to address and implement fatigue risk management in highway construction firms (i.e., contractors). These practices would also be applicable to state employees if they are not already covered by work-hour limitations in labor agreements. The upper part of the figure lists general processes for fatigue risk management, and the bottom part of the figure lists specific implementation means to institutionalize those processes. The following sections discuss each of these process and implementation steps.

Assess Corporate Approach

The first process step in addressing fatigue risk management in highway construction is identifying the current corporate approach. The most fundamental question is whether an approach to fatigue management exists. The team's field survey work suggested that managers believed their corporate safety training addressed issues of fatigue, but the team did not see any substantiating material. Instead, it seems that fatigue issues, if they are addressed at all, revolve around proper hydration and physical rest breaks in extremely hot weather, leaving fatigue from sleep loss and circadian rhythm misalignment (night work) unaddressed.

An enabling process for fatigue risk management is a corporate Safety Management System (SMS). It is likely that national-level construction firms have such systems in place, whereas smaller and regionalized firms may have more informal approaches. In either case, it is important to assess the extent to which fatigue risk management is or is not addressed. If an SMS exists, it can be reviewed for any mention of fatigue risks and mitigations and for appropriate places in which management processes might be inserted to address the problem. Existing safety processes that may be adapted and extended to the worker fatigue problem include incident investigation and reporting and worker input procedures.

While safety tends to be viewed as a shared responsibility between management and staff in organizations, there are certain roles and responsibilities in construction firms that will likely have a closer connection with worker fatigue than others. Based on the team's field research these staff roles appear to be superintendents, construction engineering planners, and labor crew supervisors. Planners have a key role in establishing specific construction tasks to be carried out, and this interacts with when they would be carried out, including the potential need for closures and night work. Superintendents tend to be aware of the pace and intensity of work and

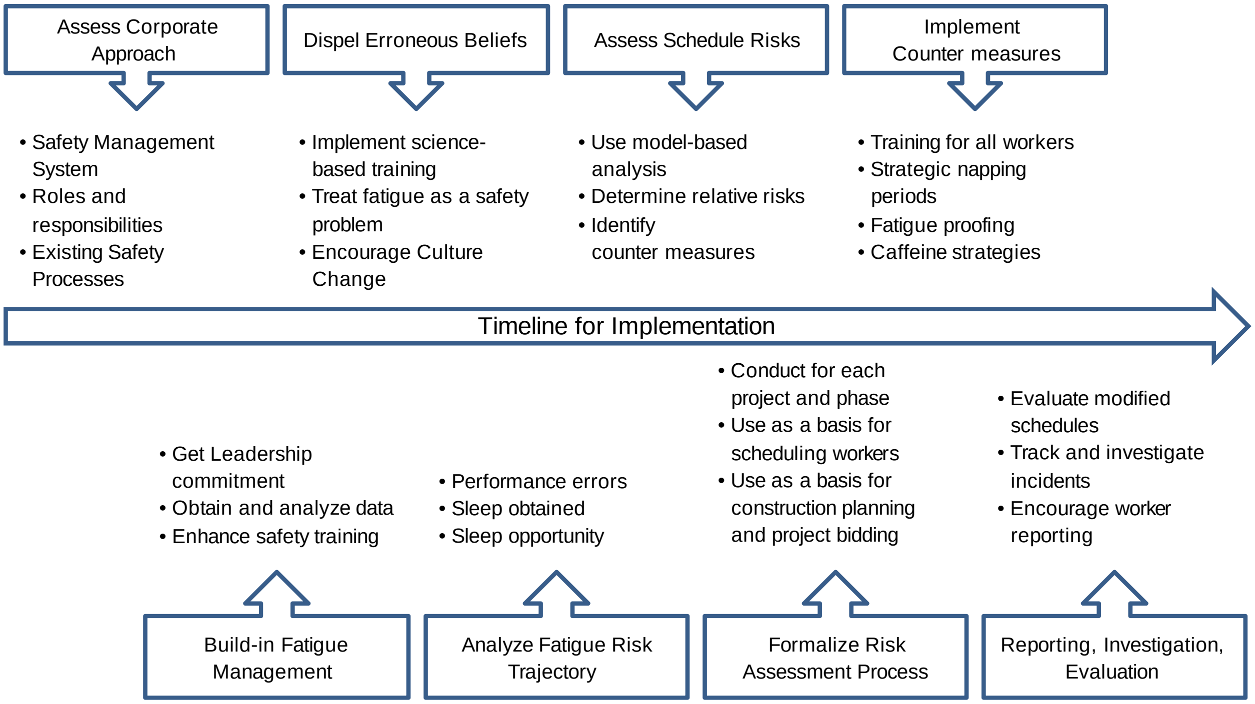


Figure 6.1. Organizational practices for implementing fatigue risk management in highway construction firms.

the likely productivity and safety impacts on workers. Crew supervisors would have a similar and more immediate understanding of fatigue issues on specific crew members.

Build-in Fatigue Management

Assessment of the basic corporate approach to safety should lead to a concrete implementation step of building fatigue management into the overall process. The initial requirement for this step is management concurrence. As in virtually all corporate initiatives, leadership commitment is essential, not only for approving whatever resources may be necessary (and this may be a relatively small amount of personnel time in most cases), but also for reinforcing messages and business practices. Changes in scheduling may impact overall performance, so fatigue mitigation should be considered by executives.

Specific methods for incorporating fatigue management in the corporate safety approach include obtaining and analyzing data and enhancing safety training. In terms of data, information that reflects on the extent to which fatigue may be a problem is important. This may be as simple as repeated verbal reports from personnel concerning scheduling issues or more detailed data reflecting productivity or safety incidents on different shifts. There will be wide variation across organizations in the nature of the data, and how they are obtained and analyzed, depending on the size and complexity of the contracting firm.

Safety training is one of the first lines of defense in fatigue management, and the team's field research suggests that existing training covers this topic only incidentally, if at all. While there are different models for training, such as new employee orientation and safety training, project-specific training, and daily crew briefings, each of these provides an opportunity to incorporate information about fatigue management. The *Guide to Identifying and Reducing Workforce Fatigue in Rapid Renewal Projects* contains an extensive compilation of training materials appropriate for both workers and management which can be adapted to specific organizational approaches.

Dispel Erroneous Beliefs

The field research identified a number of inaccurate attitudes and beliefs held by a considerable percentage of workers, and a lower percentage of management, concerning fatigue and how to deal with it. These beliefs tend to transform into "myths" over time, influencing how people think and communicate about fatigue, regardless of accuracy. Some of these inaccurate beliefs include

- Fatigue is something to muscle through;
- Fatigue management is a personal responsibility;
- Fatigue is inevitable;
- Napping is not okay in the work place; and
- Everyone has enough time off for recovery.

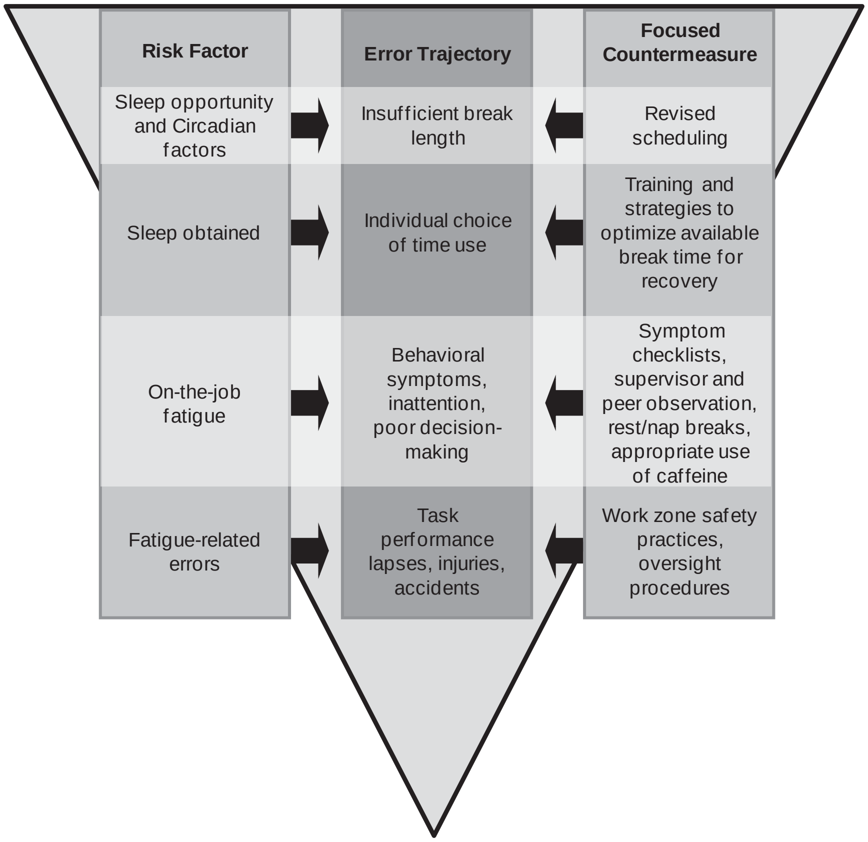
To the extent that beliefs such as these prevail and are perpetuated as myths through various elements of the workforce, fatigue will not be treated seriously. Thus, an important continuing process is to gradually dispel these beliefs and alter the cultural view of fatigue.

Science-based training can form the basis for addressing erroneous beliefs, through use of such material as provided in the *Guide to Identifying and Reducing Workforce Fatigue in Rapid Renewal Projects.* Training can help to shift the conception of fatigue from that of “inevitable annoyance” to that of “safety problem” and establish a basis for cultural change to seriously address it through fatigue risk management.

Analyze Fatigue Risk Trajectory

Implementing a process to dispel erroneous beliefs can be facilitated by using an analytic framework to clearly link safety issues in highway construction jobs with fatigue as a causal factor. The fatigue risk trajectory (Figure 6.2), based on research by Dawson and McCulloch (2005), provides a means for understanding the pathways to safety problems that can be used by safety managers for initial job/task and schedule analysis. The basic trajectory involves opportunities for sleep provided by work schedules, sleep obtained, on-the-job fatigue, and fatigue-related errors. Behavioral outcomes and countermeasures associated with these risk factors can be used as a basis for intervention.

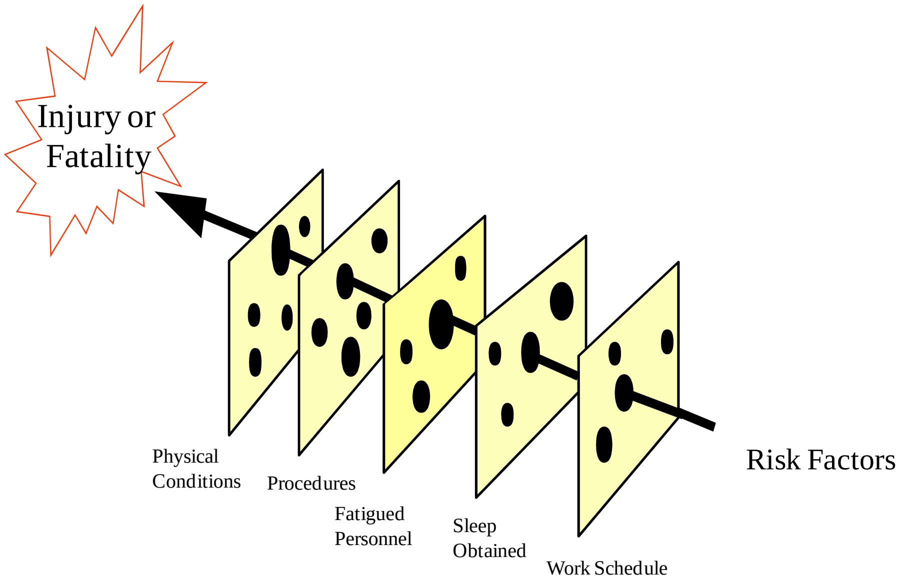
An illustration of how the fatigue risk trajectory can be used to analyze potential error-prone situations is shown in Figure 6.3 (adapted from Reason’s Swiss cheese model of accident causation; Reason 1990). Errors occur when “holes” in the defensive layers align and prevailing circumstances enhance their likelihood. An example would be a maintenance-of-traffic worker scheduled on successive 12-h night shifts, and getting less than 5 h of sleep during each off period. That individual is fatigued cumulatively throughout the week and may fail to implement traffic routing procedures correctly. Due to schedule pressures or unavailability of personnel to verify the placement of traffic routing diversions or conditions such as poor visibility or rain, this is not noticed and the result is vehicle incursion into the work zone with resulting injuries. Similar problems could occur with setting up construction equipment or rigging, putting multiple personnel at risk. Critical in this perspective on error causation is that multiple problems line up to cause an incident or accident, and fatigue is often one of those problems and therefore a risk factor to be managed and mitigated (Van Dongen and Hursh 2010).



Risk Factor		Error Trajectory		Focused Countermeasure
Sleep opportunity and Circadian factors	➡	Insufficient break length	⬅	Revised scheduling
Sleep obtained	➡	Individual choice of time use	⬅	Training and strategies to optimize available break time for recovery
On-the-job fatigue	➡	Behavioral symptoms, inattention, poor decision-making	⬅	Symptom checklists, supervisor and peer observation, rest/nap breaks, appropriate use of caffeine
Fatigue-related errors	➡	Task performance lapses, injuries, accidents	⬅	Work zone safety practices, oversight procedures

Adapted from Dawson and McCulloch 2005.

Figure 6.2. Fatigue risk trajectory.



Adapted from Reason 1990.

Figure 6.3. Fatigue risk trajectory and multiple levels of defense.

Assess Schedule Risks

A systematic approach to risk assessment can utilize knowledge of how fatigue occurs over the course of work periods for staff on various schedules. This approach can be facilitated with a computer-based model, although for most construction firms some heuristics based on model outputs contained in the Work Scheduling Guidance will likely be sufficient. A method for modeling worker fatigue levels associated with various schedules is described in the next section of this report.

The models can be used to determine likely fatigue levels for workers, based on the schedules they are assigned and how long they have been on them. This information can be used to evaluate the recovery opportunities provided by existing and planned worker scheduling. Construction planning for specific skills and crafts across the 24-h period in different phases of projects will influence worker scheduling. Planners should evaluate the impact of construction scheduling requirements in terms of worker fatigue impacts and try to ensure that work schedules dictated by construction requirements do not adversely affect individuals or groups of workers. The models can also show when commuting is likely to be a safety issue, such as the night shift, when driving home occurs at the peak fatigue level.

Fatigue profiles such as this are also useful for evaluating napping opportunities when they might occur in the work shift and their impact on fatigue levels. For example, if there is a desire to reduce peak fatigue prior to driving home after a night shift, fatigue profiles can be used to show the increase of fatigue throughout the night and provide comparative profiles with and without naps. Similarly, use of earlier work stop times on shorter night shifts can be compared with later start times to show daily peak fatigue levels and also accumulation throughout the week.

Finally, it is important to address the work hours of designers and managers, especially as they work night shifts following day shifts, or participate in long closures followed by a full week of day-shift work.

Formalize Risk Assessment Process

Implementation of the risk assessment process should eventually be undertaken as a regular activity, starting with analysis of contract opportunities and continuing through the bid, construction planning, and execution of each project phase. Since rapid renewal projects often involve alteration of construction activities due to emergent circumstances, any schedule revisions should be reviewed as well. For example, scheduling of crews involves interaction between construction engineering and crew superintendents, and to the extent that superintendents see certain work crews affected by, say, too much night work, they should negotiate the execution of various construction tasks so that the crew are provided with recovery opportunities. This may involve work breaks, naps at the work site during night shifts, re-scheduling certain tasks for day work if possible, increasing staffing, and generally providing relief from constant night work.

Fatigue risk assessment can also be used as a formal process for construction planning, as well as for determining schedule and fatigue impacts of projects in the bid evaluation stage. For example, if a request-for-proposal contains incentives for completion or a specific number of closures permitted, modeling could be used to determine the work schedules required, availability of crew for such schedules, and potentially whether the project warrants bidding. If schedule modeling were to show night work at a level that management considers unsustainable, alternative approaches might be proposed.

Implement Countermeasures

Countermeasures for fatigue are an important component of an overall organizational approach. The primary countermeasure is education and awareness for all personnel, including management, to dispel the myths and erroneous beliefs about fatigue, and to instill an understanding of the biological basis of fatigue and the things that can be done about it.

A few key countermeasures have been found to be effective in a variety of industrial environments, including defensive napping prior to night work and napping at appropriate times during the work period (such as the lunch break), caffeine during periods of high fatigue or to reduce sleep inertia (the fatigued feeling upon waking) after mid-shift naps, rest breaks from the work flow, and using scheduling to try to accommodate individuals who have varying susceptibility to fatigue.

One potential approach to a work break is to consume a caffeinated beverage just before a 30-min nap, and at the end of the nap the caffeine will be starting to take effect. If the caffeinated beverage is cold rather than hot, this may facilitate rapid consumption if time for the nap is limited. This approach will have the dual impact of reducing sleep inertia and reducing fatigue for the following several-hour period.

The team suggests implementing countermeasures as a relatively continuous process, rather than a discrete implementation step. This is because conditions in rapid renewal projects are dynamic, and the specific approaches to implementation may vary with the schedule and season. For example, night work might be scheduled for a somewhat earlier start in the summer months, leading to a work stop time that allows workers to get home and into bed before it is completely light outside. It has been reported in the team's field work that this facilitates getting to sleep faster and sleeping somewhat longer, and this observation is supported by circadian physiology.

Fatigue countermeasures involve not only mitigating fatigue through rest breaks, better sleep opportunities, and so forth, but also addressing the fact that fatiguing schedules cannot be entirely eliminated. Night work is a fact of life in rapid renewal highway construction. In addition to addressing fatigue-reducing countermeasures, there are fatigue-proofing strategies for adding layers of defense against error. These include

- Increased supervisory oversight;
- Use of written procedures and checklists;
- Self- and peer-monitoring during critical periods;
- Reducing monotonous or highly complex tasks during periods of high fatigue;
- Extra personnel for critical and dangerous tasks;
- Nap timing for best impact;
- Interaction with peers to evaluate fatigue levels;
- Self-selected rest breaks;
- Transportation assistance following extended shifts; and
- Training for workers and managers in how to recognize fatigue.

By continually evaluating schedules and conditions of work, safety managers can adapt both fatigue-mitigating and fatigue-proofing countermeasures to prevailing conditions.

Reporting, Investigation, Evaluation

The role of fatigue in construction safety problems is probably under-represented due to lack of reporting and investigation. A proactive management approach to fatigue should encourage workers to report problems, whether they are related to scheduling, specific tasks, or even other workers.

In order to better understand specific project fatigue problems, safety incidents should be investigated with the fatigue factor in mind, including whether night work was involved and individuals worked many successive night shifts without a break, whether a weekend closure was involved, and whether the individual workers were experiencing sleep restriction or sleep problems.

Commuting accidents, although technically not occurring during duty hours, can sometimes be related to fatigue from night work, and are especially likely during rush traffic in the morning.

Information collected can be useful in modifying work schedules. A primary issue in implementing this step relates to the availability of data, determining what the current procedures are, if any, to document and investigate incidents and accidents. This will vary considerably across organizations based on their size and complexity. Trade and government organizations may play a role in providing standards and tools for structured data collection efforts.

The role of sleep disorders in contributing to workplace fatigue should not be ignored. In the field survey, eight (17%) out of 47 survey respondents reported having been diagnosed with a sleep disorder in the past, but only half reported receiving treatment. Sleep disorders are associated with excessive daytime sleepiness and increased prevalence of motor vehicle accidents and occupational injuries (Findley et al. 1988; Aldrich 1989; Chau et al. 2004; Chau et al. 2004). The majority of shift workers have a sleep disorder (Leger 1994), and some sleep disorders can be caused by shift work (Guilleminault et al. 1982). Common sleep disorders include insomnia, restless leg syndrome, and obstructive sleep apnea. Obstructive sleep apnea is particularly prevalent among men between the ages

Adapted from Gander et al. 2011.

Figure 6.4. Integrated elements of fatigue risk management system.

of 30 and 60, a risk that increases if they are overweight (Bixler et al. 1998). Evaluation and treatment of sleep disorders has benefited the trucking industry.

Summary of Organizational Practices

Figure 6.4 shows how to integrate the organizational practices described in this section. An overarching safety management system can be anything from informal processes conducted by an individual part-time safety officer in a small firm, to a more formalized structure with procedural mechanisms and formal reporting documentation and channels in larger organizations. The fundamental outputs of the organizational practices are the same: a deliberate and rational method for addressing and mitigating the impacts of fatigue on operational personnel.

Training Material

Two training modules were developed: a basic fatigue training program intended for all workers and a training program intended for managers and other supervisory personnel. The general objectives of training include the following:

- Raise awareness of the fatigue issue, particularly as it pertains to rapid renewal work schedules.
- Establish a knowledge base for understanding and responding appropriately to fatigue issues.
- Provide workers and managers with specific strategies and tools for avoiding fatigue or reducing and mitigating the effects of fatigue on the job.

Detailed training material content is contained in the *Guide to Identifying and Reducing Workforce Fatigue in Rapid Renewal Projects.*

Basic Training

The Basic Fatigue Training is intended for use by all persons involved in highway construction, including laborers, supervisors, managers, designers, and DOT personnel. Ideally, it should be completed by managers and other relevant personnel before completing the manager training. Basic training provides an introduction to fatigue concepts (e.g., circadian cycle and sleep debt), explains the causes and consequences of fatigue, and outlines practical strategies (individual countermeasures) for preventing, recognizing, and managing fatigue at work. The training begins with a set of learning goals, and each module concludes with questions for discussion or personal consideration, intended to encourage workers to evaluate the concepts in light of their own experiences and to apply strategies based on their own needs. Information is tailored specifically to the demands of the highway construction environment; however, the training content is also broadly applicable and will be relevant to workers in organizations with different roles and contexts.

Manager Training

Manager training summarizes some of the basic fatigue material but is meant to provide a larger organizational context, processes, and implementation steps for addressing fatigue risk management. The focus is on schedule risk assessment in terms of sleep disruption and how various schedules are used in different phases of project execution. Illustrations of fatigue impacts based on work schedule models are provided, and there is considerable discussion of the relationship between safety management as it is currently implemented and how fatigue risk management might fit in. The training is meant to convey an understanding of the basic processes and steps of fatigue management, and it encourages participants to evaluate their own organizations to determine how these approaches might be implemented. There is wide variation in construction company size and complexity but fatigue management is an important issue across these variable contexts. One approach will not fit all circumstances, but the training conveys a series of analytic questions that will allow participants to evaluate their unique organizations and adapt fatigue risk management methods accordingly.

Work Scheduling Aids and Work Practice Guidance

Work scheduling and work practices guidance was developed to address worker fatigue associated with different schedules used in rapid renewal highway construction. The basic form of this guidance consists of schedules illustrating employees' work start–stop times and sleep–wake times for each day of the week, fatigue profiles over the 24-h period for the week-long schedule, and recommended fatigue mitigations for each schedule. In this section, the team first discusses the basic variations of rapid renewal scheduling and the factors that influence work schedules, then provides a discussion of a sample of the work schedule and work practices guidance contained in the *Guide to Identifying and Reducing Workforce Fatigue in Rapid Renewal Projects.*

Rapid Renewal Schedules and Implementation Considerations

The most common types of work-hour scheduling for highway construction contractors include

- Daytime construction;
- Nighttime construction;
- Continuous construction; and
- Combinations of the above.

Weekday daytime construction generally does not involve major lane closures for urban highways in order to avoid congestion associated with a traffic shift. In this case, the contractor maintains its construction work behind K-rail with traffic pushed to the side. In rural areas, daytime construction can be performed with a lane closure in place, with the contractor performing work behind traffic barriers (such as rubber cones or plastic barrels), as long as the lane closure does not cause major traffic congestion.

Nighttime construction typically involves some degree of lane closure, with short closures of 5 to 7 h for highly congested urban areas, longer closures of 8 or more hours for urban areas with less traffic density, and extended closures of up to 11 h for rural locations.

Continuous construction involves major lane closures in urban areas to perform large-scale renewal work.

The practical implementation of work scheduling by contractors for specific projects depends on the lane closure guidelines and requirements specified in the sponsoring agency's transportation management plans, or management of ongoing traffic. In general, a state DOT develops lane closure charts (also called "lane open charts" or "lane requirement charts") for a highway renewal project as part of the transportation management plan. The lane closure charts dictate how many lanes can be closed for construction during specified hours (alternatively, the lane open charts show how many lanes are required to be open for each hour). In addition to these constraints, contractor work-hour schedules are influenced by (1) working days estimated by the state DOT for the bid, (2) Cost + Schedule (so-called "A + B") contract elements, and (3) incentives and disincentives in the contract. Additionally, the type of work to be performed at various phases of construction (such as bridge or utility work) is combined with these three primary project management elements.

Work Schedule Fatigue Modeling

A critical piece of information for managing worker fatigue is understanding the combined influence of biological rhythms, work schedule, and sleep patterns on fatigue during the work period. By understanding these variations, managers and engineers can address problems through various countermeasures and interventions to mitigate fatigue.

The team developed fatigue profiles for 20 basic schedules (5 day schedules; 5 nights; 4 closure weekends; 4 switching shifts; 2 manager/designer) that may be encountered in rapid renewal construction, with variations based on applications of countermeasures, for a total of 107 models. This section discusses the technical basis for these fatigue model profiles, illustrates how they can be applied, and discusses the general categories of risk factors and countermeasures (work practices) that may be applied.

Fatigue Modeling Technical Basis

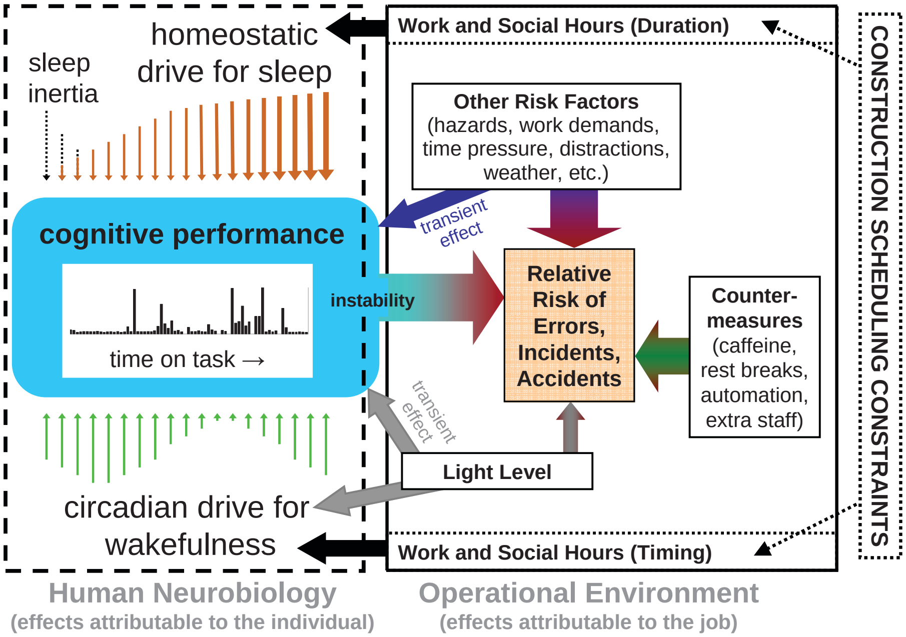
Based on a recent literature review, Dawson and McCulloch (2005) determined that work schedules resulting in the following conditions would be inconsistent with safety in the workplace:

- Less than 5 h of sleep in the prior 24 h;
- Less than 12 h of sleep in the prior 48 h; or
- Longer wakefulness than the total amount of sleep obtained in the prior 48 h.

However, this rule of thumb depends critically on prior circumstances, most notably on the circadian timing of the work period. A more scientifically valid and operationally optimal approach makes use of a mathematical model of fatigue to forecast the fatiguing effects of a work schedule (Raslear et al. 2011). This is the basis of model-based fatigue risk management (Van Dongen and Belenky 2012), which is gradually gaining widespread acceptance in U.S. operational settings.

The model used for the illustrations in this report is an expansion of a biomathematical model of fatigue developed by McCauley et al. (2009). This model is the first to incorporate the neurobiology of long-term changes in the homeostatic equilibrium for sleep/wake regulation—in other words, changes in sensitivity to future sleep loss due to exposure to sleep loss in the recent past. In the expanded version of the model used here (McCauley and Van Dongen 2012), the circadian rhythm in the effects of fatigue interacts dynamically with the homeostatic changes to accurately predict the fatiguing effects of sleep loss in night work operations. The model is calibrated to predict lapses on the psychomotor vigilance test (PVT) (Lim and Dinges, 2008), a gold standard measure of fatigue, based on three large data sets from published laboratory studies of sleep loss and circadian misalignment and validated using another three such data sets. The resulting profiles may be considered to reflect the overall rise and fall of an underlying construct, fatigue, which is correlated with more performance errors, reduced subjective alertness, and increased likelihood of falling asleep.

It is tempting to think of fatigue model output as defining hard constraints concerning when a person is sufficiently rested versus too fatigued to work. However, fatigue models are not meant to be employed in this way for several reasons. First, while there is an association between fatigue and safety incidents, the existence of fatigue does not always lead to accidents; a fatigue-related error must coincide with a safety-critical condition to result in an accident. Second, there are individual differences in susceptibility to fatigue and performance effects; models provide results for a statistical average. Finally, the risk associated with a given level of fatigue depends also on the task at hand, the operational circumstances, and the tolerance level for performance impairment and errors (see Figure 6.5). The model outputs are meant to contrast fatigue in terms of relative risk, that is, the likelihood that various schedules will



Original graphic created by H. P. A. Van Dongen June 2012.

Figure 6.5. Neurobiological and operational determinants of fatigue illustrating interaction between physiological and work factors, relative risks, and performance outcomes.

induce greater or lesser degrees of fatigue based on the interaction of multiple work schedule factors.

Fatigue models provide a guide to schedules and times of day that are more likely to be associated with fatigue and safety problems. However, like traffic and weather forecasts, fatigue models are not predictive for any one individual, schedule, or project in an absolute sense. Whereas models do not (and, by definition, cannot) provide strict assessments of whether a given schedule is safe or unsafe, they are very useful as tools to evaluate planned schedule improvements that will help reduce fatigue, suggest good practices for administration of fatigue countermeasures, and guide decisions about appropriate tasking and level of supervision based on the relative fatigue likelihood associated with a schedule.

Table 6.1 shows the basic schedule combinations the team modeled for generic shift scenarios. The scenario combinations were reported during the field research. The main purpose of the schedule modeling was to assess variations in fatigue that are manifest from fundamental changes in schedule, such as day versus night work, as well as from more subtle influences such as the impact of consecutive days or nights of work, strategic napping, and sleep–wake schedule maintenance during days off.

The team made several assumptions when modeling schedules:

- All schedules include a 1-h commute each way and a 30-min meal break.
- Commute time is not included in work or sleep time, but meal breaks are included in work time (i.e., time "on duty") such that a "10-h" shift takes place over 10 h, 30 min.
- Day shift schedules allow 30 min in the morning for personal tasks between waking up and leaving for work.

Table 6.1. Scenarios, Assumptions, and Variables Used in Work Schedule Fatigue Modeling

Scenario	Assumptions	Schedule and Countermeasure Variables Modeled
Day Shifts	• 30-min meal break • 1-h commute • 7.5 h sleep nightly • 7:00 a.m. start time	• Length of day (7, 8, 10, 12 h) • Length of week (40, 48, 50, 55, 60 h) • Alternating Saturday work
Night Shifts: 5, 7, 8, 11 h closures	• 30-min meal break • 1-h commute • 1:00 p.m. wake time	• Length of day (8, 10, 11, 12 h) • Length of week (40, 48, 50, 55, 60 h) • Naps at work • Defensive nap at home before night shift • Reversion to day schedule on days off vs. maintenance of night schedule
Weekend Closure: 55 h	• 30-min meal break • 1-h commute • 1:00 p.m. wake time when on nights • 7.5 h sleep nightly when on days • 7:00 a.m. start time when on days • "Standard" 5 × 10 schedule during week with 12-h shifts on weekend	• All day shifts • All night shifts • Day shift during week switching to nights over weekend closure • 12 days straight vs. 1 day off • Naps at work when on nights • Defensive nap at home before night shift
Switching Shifts	• 30-min meal break • 1-h commute • 1:00 p.m. wake time when on nights • 7.5 h sleep nightly when on days • 7:00 a.m. start time when on days • 10-h shifts	• Days to nights over weekend off • Days to nights midweek with day off • Days to nights midweek without day off • Nights to days over weekend off • Nights to days midweek with day off • Nights to days midweek without day off • Naps at work when on nights • Defensive nap at home before night shift
Manager and Designer	• 30-min meal break • 1-h commute • 7:00 a.m. start time	• Manager 55-h week, 7.5 h sleep nightly • Designer 50-h week, 7.5 h sleep nightly • Designer 80-h week, 6 h sleep nightly
Anchor Sleep Schedules	• 30-min meal break • 1-h commute • Day shift • 6.5 h sleep nightly for laborer	• Manager weekend closure • Laborer, 6:00 a.m. start (5 × 10) with after-work nap • Laborer, 5 × 12 day shift with nap at work
Restricted Sleep	• 30-min meal break • 1-h commute • 5 × 10 day shift • 7.5 h sleep nightly when not disrupted	• 1 night of 4.5 h sleep • 2 consecutive nights of 4.5 h sleep

- Night-shift schedules allow 1 hour in the morning between arriving home and going to bed, for personal tasks and "winding down" after work.
- Personal task periods are not included in sleep time or work time.
- Day shift schedules assume 7.5 h of sleep per night, unless otherwise noted, regardless of shift duration.
- Night-shift schedules assume a wake time of 1:00 p.m. between night shifts due to circadian pressure to wake at this time; hours of sleep obtained are therefore determined by the end of shift.
- The final night shift in a week is followed by a morning nap of 2 h if reverting to a day schedule on days off.

Detailed modeling results are contained in Appendix D. The following section summarizes the results from the schedule modeling.

Illustrative Model Results

Figure 6.6 through Figure 6.8 show sample results from models of day and night shifts, with a work week consisting of five

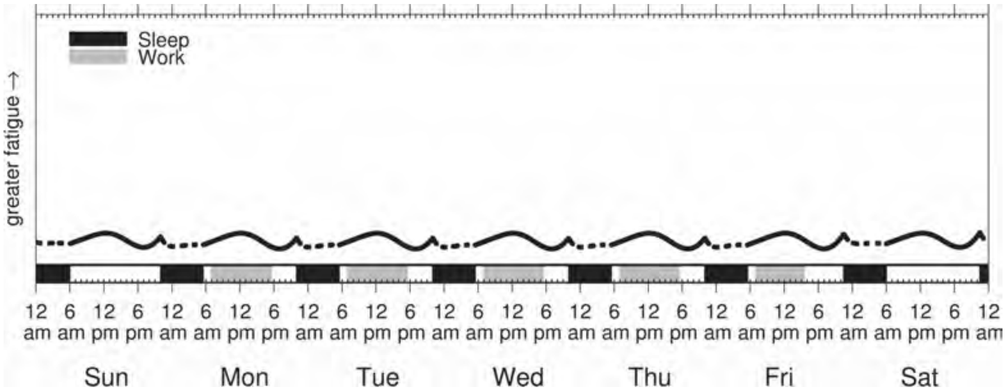


Figure 6.6. Fatigue profile: 5 × 10 (50-h week) day shift.

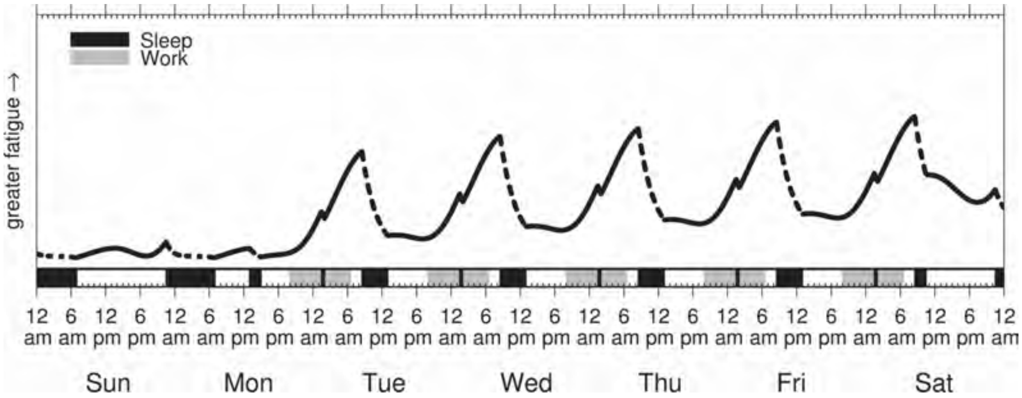


Figure 6.7. Fatigue profile: 5 × 10 (50-h week) night shift with mid-shift and defensive naps.

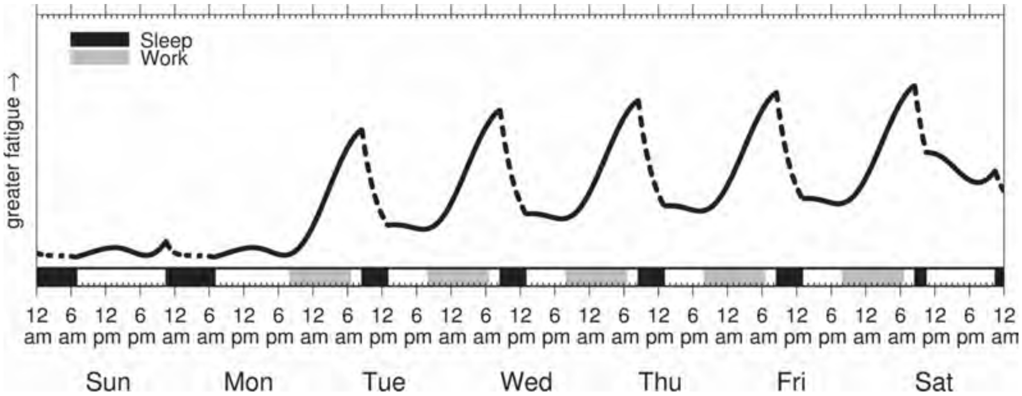


Figure 6.8. Fatigue profile: 5 × 10 (50-h week) night shift without naps.

10-h days, Monday through Friday. Work start and stop times are illustrated, as is the sleep period. These shifts were chosen because they illustrate common phenomena that occur across schedules. Three 50-h week shift variations are depicted: 5 × 10 day shift (Figure 6.6); 5 × 10 night shift ending at 6:30 a.m., with mid-shift naps and defensive naps (Figure 6.7); and 5 × 10 night shift ending at 6:30 a.m. with no naps (Figure 6.8). Note that fatigue plots and bar graphs in this chapter employ consistent vertical scales.

Initial inspection of the model output shows that there is a substantial difference in overall fatigue levels between day and night shifts. While there is variation in fatigue level in the day shift (Figure 6.6), both the peaks and troughs for the night shift are substantially higher than for day shift, and the difference between the peaks and troughs is much greater on night shift.

The day shift shows a rise in fatigue that peaks just after noon, with a decline toward early evening followed by a sharp rise just before bedtime, and no accumulation of fatigue throughout the week (Figure 6.6).

On the night shifts (Figure 6.7 and Figure 6.8), fatigue rises throughout the work period and the commute home and peaks at bedtime. Part of this effect is accounted for by the lower amount of sleep typically obtained by night shift workers—5 h, rather than 8 h (Åkerstedt 2003)—due to difficulty sleeping during that portion of the circadian cycle. The overall effect of this is cumulative; fatigue is higher on successive days of the week, reaching its maximum at bedtime following the last 10-h shift. A mid-shift nap of 30 min each night and a defensive nap the afternoon before the first night shift reduces peak fatigue each night and the cumulative effect throughout the week (Figure 6.7), relative to no naps (Figure 6.8).

Figure 6.9 compares the peak fatigue reached after start of the work period for each of the schedule models shown in Figure 6.6 through Figure 6.8. The differences in peak fatigue and cumulative effects between schedules are more evident here.

Figure 6.10 through Figure 6.12 contrast day shift fatigue profiles under three different conditions: normal sleep of 7.5 h and 1 or 2 nights of restricted sleep (4.5 h each night). The restricted sleep occurs on Sunday (Figure 6.11 and Figure 6.12) and Monday nights (Figure 6.12 only), and resulting higher levels of fatigue week relative to the profile with no restricted sleep (Figure 6.10) can be seen on Monday and throughout the rest of the week. The impact of 2 nights of restricted sleep leads to the highest levels of fatigue on subsequent days, and the effect lasts longer (see Figure 6.13 for a comparison of peak fatigue levels). It takes more than a single good sleep period to recover from 1 night of serious sleep deprivation, and more still for 2 nights. These results suggest that project managers should pay close attention to the potential longer-term impacts of short-term sleep restriction.

Modeling Summary and Work Practice Guidance Implications

This section discusses the work schedule modeling findings that are the most significant for influencing work practices such as scheduling decisions, shift start and stop times, closure lengths for various construction phases, and specific fatigue countermeasure implementation within a schedule.

Daytime Construction

Daytime construction schedules are preferable as a means of minimizing fatigue and obtaining adequate recovery sleep.

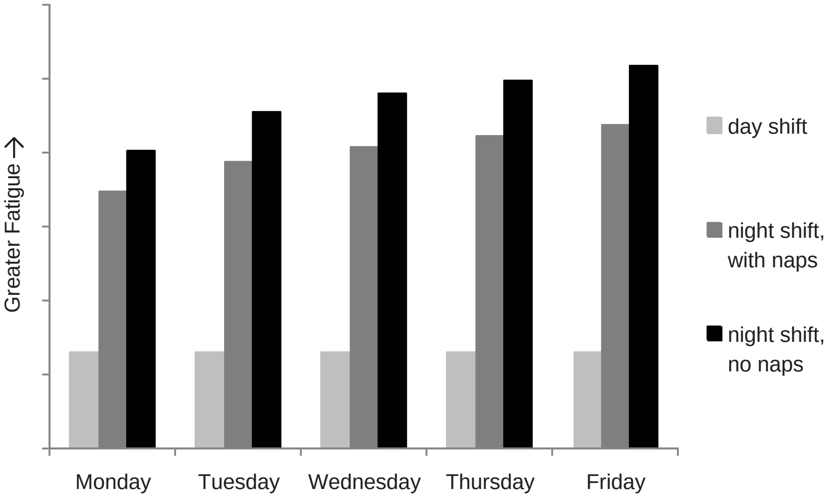


Figure 6.9. Peak fatigue: 5 × 10 (50-h week) day shift and night shift with and without naps.

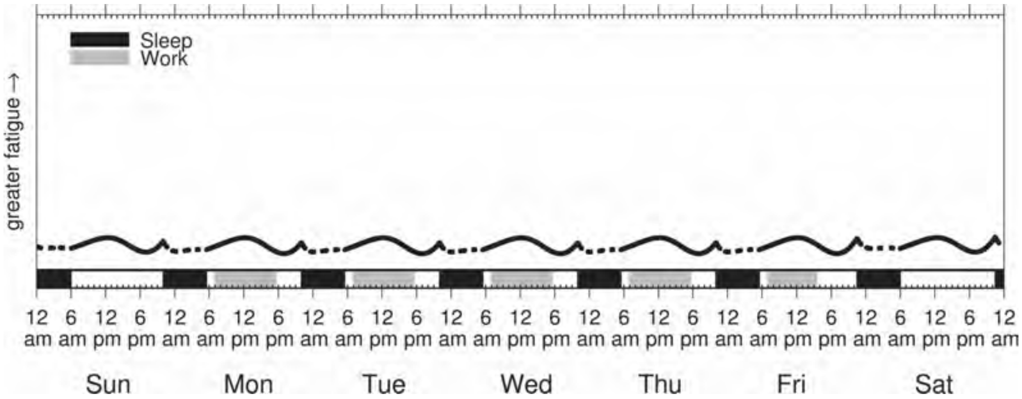


Figure 6.10. Fatigue profile: day shift with normal sleep (7.5 h per night).

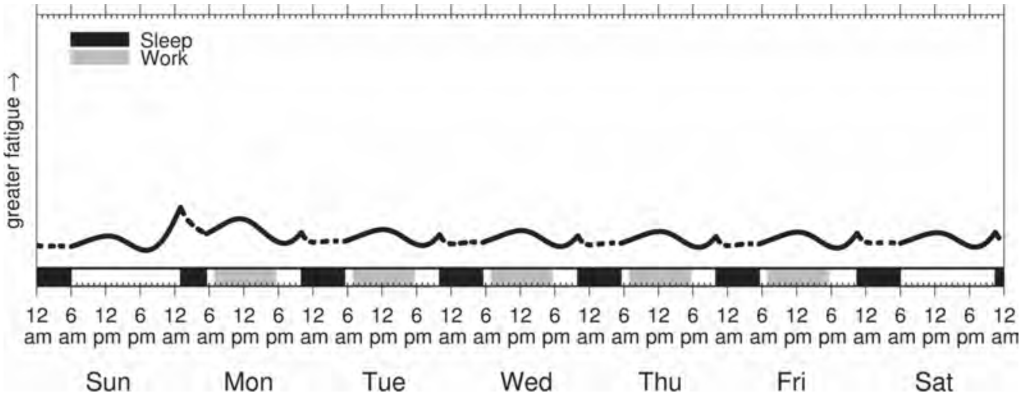


Figure 6.11. Fatigue profile: day shift with 1 night restricted sleep (4.5 h).

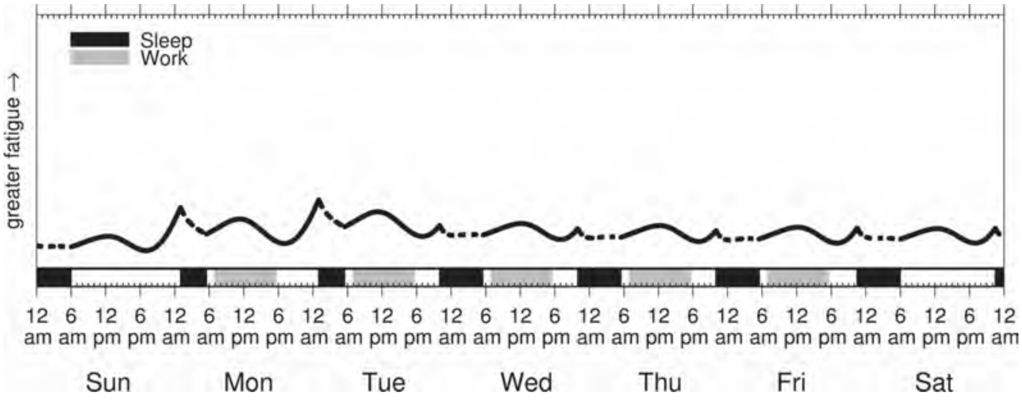


Figure 6.12. Fatigue profile: day shift with 2 nights restricted sleep (4.5 h).

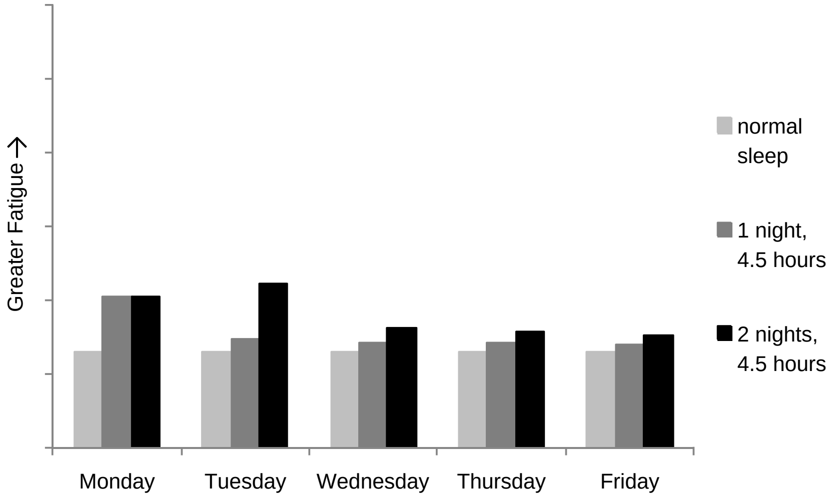


Figure 6.13. Peak fatigue: day shift with normal sleep (7.5 h per night) and 1 and 2 nights restricted sleep (4.5 h).

Models of daytime construction schedules (40 to 60 h per week) show no differences in fatigue profiles across shift type or throughout the week, assuming 7.5 h sleep per night. Fatigue level peaks in the early afternoon and rises again sharply just before bedtime. In practice, however, fatigue is likely to increase as shifts get longer. The longer the shift, the less off-duty time is available for daily tasks (e.g., personal care, parenting, household chores), and sleep may be sacrificed to accomplish these.

Nighttime Construction

Nighttime construction schedules of all variations show fatigue levels substantially higher than day schedules due to reduced sleep opportunity based on circadian pressure for wakefulness during the day (see Figure 6.9 for an example). Fatigue rises continuously throughout the night-shift work period and the commute home, peaking at bedtime (about 1 h after arriving home, according to the team's models). Furthermore, nighttime construction schedules of all variations show a cumulative fatigue effect since reduced sleep hampers recovery (as in Figure 6.7 and, especially, Figure 6.8).

Fatigue in night schedules is exacerbated by later work stop times and can be reduced through earlier stop times, such as 4:30 a.m. (Figure 6.14). Extended night shifts (10 h or more) tend to end later than shorter shifts and can result in severe sleep restriction (5 h or less) due to circadian pressure to wake around 1:00 p.m. For this reason, extended shifts should not be used on a regular basis for the same crew.

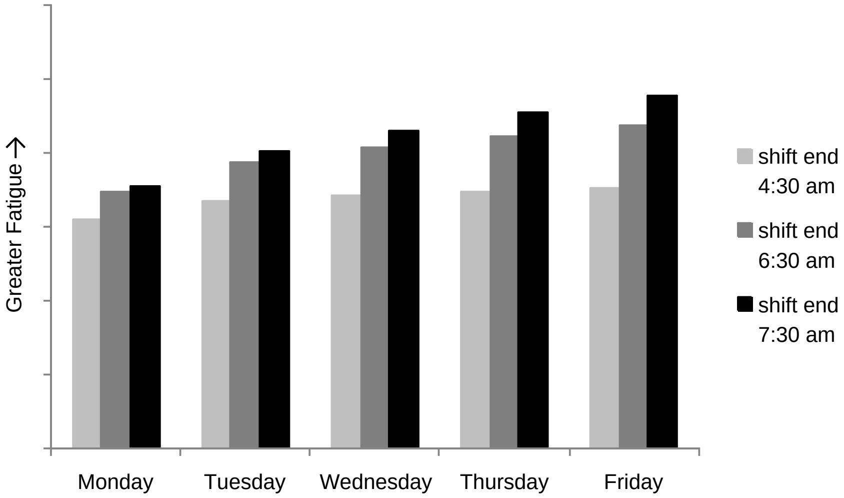


Figure 6.14. Peak fatigue: night shift with various work stop times.

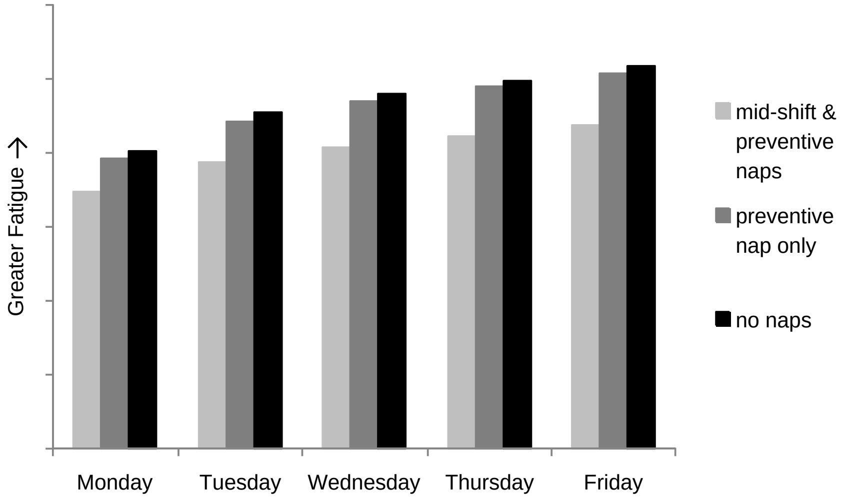


Figure 6.15. Peak fatigue: 5 × 10 (50-h week) night shift with and without mid-shift and defensive naps.

Taking naps is effective in reducing fatigue while working night shifts. A mid-shift nap on night schedules, even when short (30 min), is the single most effective fatigue countermeasure. It reduces peak fatigue and lowers the cumulative effect across days. A longer defensive nap (2 h) in the afternoon before the first night shift in a week is also helpful in reducing fatigue. Night shifts of any duration are substantially more fatiguing without these naps; a 5 × 10 night shift schedule is used as an example (Figure 6.15).

In summary, a night shift schedule organized to accommodate maximum recovery opportunity would end early and allow workers to take naps. Figure 6.16 compares peak fatigue for a typical day shift with "best-case" and "worst-case" night-shift scenarios, the best-case scenario being a shift that ends at 4:30 a.m. with workers taking mid-shift naps and a defensive nap, and the worst-case scenario being a night shift that ends at 7:30 a.m. and workers taking no naps. The best-case night shift scenario still results in peak fatigue that is at least double that of a typical day shift. However, by the end of the work week, the worst-case night shift scenario results in peak fatigue approaching twice that of the best-case night-shift scenario, as well as a substantially more rapid accumulation of fatigue throughout the week.

Finally, the team's fatigue models showed no substantive difference in fatigue levels for night-shift schedules where the worker reverts to a day schedule on days off (sleeping at night

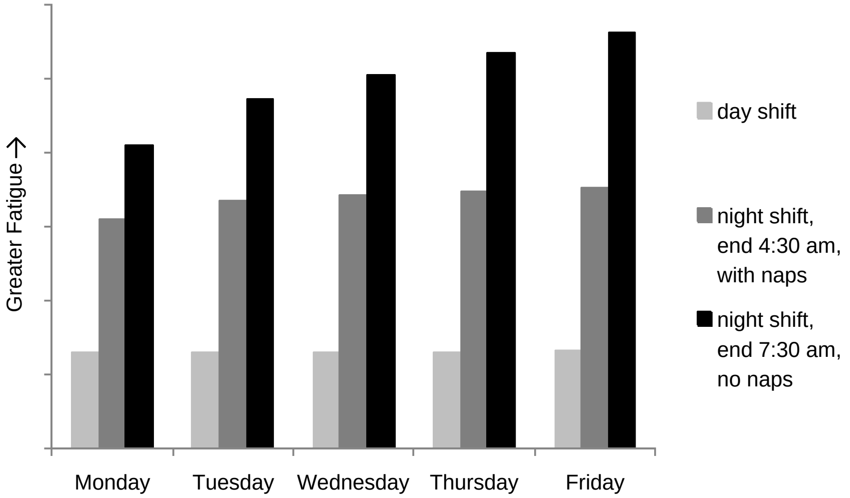


Figure 6.16. Peak fatigue: day shift versus best-case and worst-case night-shift schedules.

following a long morning nap after the last night shift) compared to maintaining a night schedule (sleeping 8 h during the day). However, it may be advantageous for workers to revert to a day schedule on days off, even if they will be returning to a night-shift schedule the following week, for two reasons. First, keeping a more "normal" schedule on days off will allow them to participate in many activities that are difficult while on a night shift, including family and social activities. Second, sleep quality for most individuals is poor during the day, even when the number of hours in bed would seem sufficient for adequate recovery. Little, if any, adjustment of the circadian rhythm to a night-shift schedule is expected unless such a schedule is maintained for many weeks and light/dark schedules can be reversed. Other than indoor on oil platforms and in space, this is usually not feasible (Van Dongen, Belenky and Vila 2011).

Shift Switching and Weekend Closures

Granting workers a day off (i.e., a full 24 h between the end of one shift and the start of the next) when switching from a night-shift schedule to a day-shift schedule (or vice versa) is preferable to using double shifts or shifts with a very short break between. This is true for both mid-week shift switches and for short-term shift switching that occurs as a result of a weekend closure. For example, when workers who are usually on day shift are chosen to cover night shifts for a continuous weekend closure, a full 24-h break at each switch provides the best recovery opportunity.

Managers and Designers

Managers wishing to maintain high levels of on-site presence during weekend closures can reduce fatigue by engaging in two separate sleep periods ("anchor sleep" or "split sleep")—a longer one of at least 4 h at night (the anchor sleep period), and a shorter one of 2.5 to 3 h (a supplemental nap) during the day (Mollicone et al. 2008). A manager the team interviewed reported his work and sleep periods during a recent weekend closure, and using this as a model, the team constructed an anchor sleep schedule that would have allowed the same number of hours at work with regular presence on site during both day and night shifts. Peak fatigue could be reduced considerably using the alternative, anchor sleep schedule (Figure 6.17).

Designers (or engineers) working high production schedules of 80+ h per week are vulnerable to cumulative sleep reduction and increasing fatigue. Fatigue levels are higher than for a standard day shift due to substantially reduced sleep opportunity while working very long (up to 14-h) days, and peak fatigue increases gradually throughout the week (Figure 6.18). Tactical countermeasures such as strategic naps and self-selected breaks can reduce the immediate impacts, but this type of schedule should not be sustained.

Restricted Sleep

A single night of sleep restriction leads to increased fatigue on the day shift for several subsequent days, and 2 nights leads to even greater fatigue (Figure 6.13). Acute sleep restriction (sleep loss) can occur for many reasons, including illness, household pressures, or emotional stress. Recovery frequently takes more than a single full night of sleep.

Daytime construction schedules with unusually early start times (e.g., 6:00 a.m.) or long shift durations (e.g., 12 h) may result in curtailed sleep periods. Increased fatigue can be avoided by taking naps at mid-shift or after work. After-work naps should begin before 6:00 p.m. to avoid the circadian high-alert period that begins in the early evening. If naps are

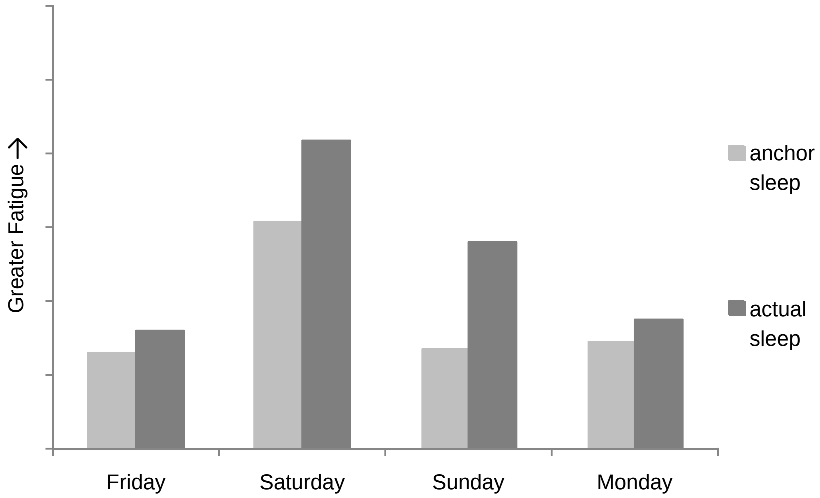


Figure 6.17. Peak fatigue: manager's actual versus possible anchor sleep schedule for 55-h weekend closure.

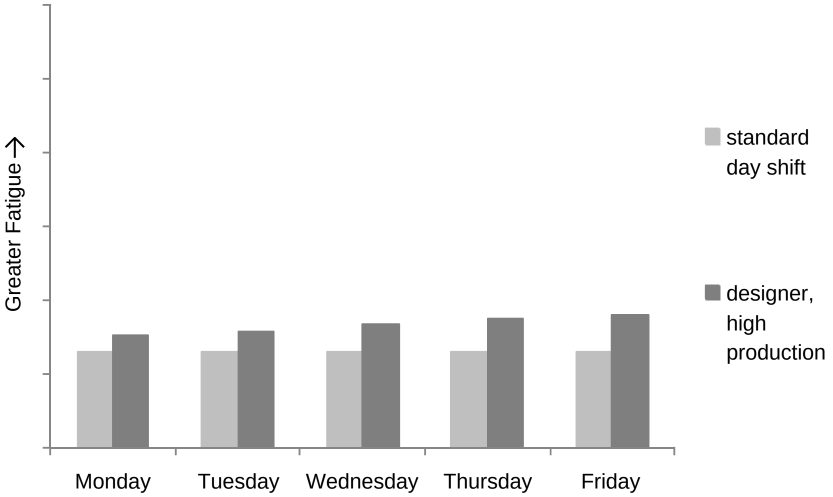


Figure 6.18. Peak fatigue: high production designer or engineer schedule versus typical day schedule.

not used to alleviate excess fatigue, the peak fatigue trajectory of such a worker will be similar to that of high-production designers (Figure 6.18).

Caffeine Use

Caffeine can be used effectively before and during a shift for relief from acute fatigue. Caffeine is most effective when used sparingly; on day shift, it is most useful in the morning and during the "post-lunch dip" in early afternoon. Consumption should cease at least 5 h before bedtime, though there are large individual differences in caffeine impact.

Sleep inertia experienced upon waking from mid-shift naps may be counteracted with consumption of a caffeinated beverage before the nap, which will take effect as the nap is ending (Reyner and Horne 1997; Van Dongen et al. 2001). This may be particularly useful on night shift, when workers may be concerned about their ability to awaken fully from a mid-shift nap. A cold, rather than hot, caffeinated beverage may facilitate rapid consumption prior to the nap.

Table 6.2 provides a structured comparison of the schedules and countermeasure variations modeled, the major fatigue findings, and work practice implications.

Summary of Work Practice Recommendations

The most practical approach to work practice guidance for contracting firms is to use the findings from work schedule fatigue modeling to plan construction activities that incorporate knowledge of fatigue's impact on workers. Work practice guidance to address fatigue is a blend of specific tactics and countermeasure implementation, such as caffeine usage and worksite napping, and broader organizational practices associated with systematic evaluation and management of the problem. Unlike specific worksite problems such as traffic management or visibility, which can be addressed with procedures or technology such as lighting, work practices for fatigue management involve individual, crew, and organizational-level interventions.

This intersection is best illustrated by the fatigue impacts associated with extended night shifts of 10 h or more. These shifts lead to severely curtailed sleep, because of reduced sleep opportunity and circadian pressure for wakefulness during the day. In general, the team recommends limited use of this type of schedule, since it leads to chronic sleep restriction during a multi-day schedule. Sleep restricted to 3.5 to 6.5 h per 24-h period, as modeled, leads to high levels of fatigue and cumulative effects on the worker. Thus, while construction exigencies may require 12-h work periods or longer during a night closure, an organizational commitment to fatigue management would suggest that such a schedule be used only when it can be followed by an appropriate recovery period for the workers affected, or when other countermeasures can be implemented.

More generally, the team would expect that the work schedule and work practice guidance described in this chapter and detailed in the *Guide to Identifying and Reducing Workforce Fatigue in Rapid Renewal Projects* can serve as a resource for project planners and work crew superintendents to manage the assignment of crew to specific shifts and construction tasks. By using the schedule guidance in combination with awareness training and fatigue countermeasures, planners and superintendents can address fatigue issues such as cumulative sleep loss effects on the night shift before they become excessive. While the team does not suggest that construction projects be planned exclusively around worker fatigue management, the availability and use of fatigue

Table 6.2. Structured Comparison of the Schedules and Scenarios Modeled, the Major Fatigue Findings, and Work Practice Implications

Scenario	Major Fatigue Findings	Work Practice and Countermeasure Approaches
Day Shifts	• No substantive fatigue differences across week or shift types • Fatigue increases to mid-afternoon, declines toward evening, increases before bedtime	• Caffeine during day, but no later than 4:00 p.m. • Maintain consistent sleep and wake times throughout the week if possible • Maintain similar or identical sleep and wake times on weekend or non-work days • Strategic naps (on-the-job) to reduce impact of restricted sleep • Consume caffeine just before strategic naps to counteract sleep inertia on waking • Self-selected rest breaks to reduce fatiguing impacts of monotonous tasks or highly complex tasks
Night Shifts: 5, 7, 8, 11-h closures	• Sleep durations significantly shorter than day shifts because of circadian rhythm influences: 3.5 to 6.5 h due to circadian pressure to wake around 1:00 p.m. • Mid-shift nap substantially reduces peak fatigue within and across shifts, and reduces cumulative effects	• Minimize use of extended shifts (10 to 12 h) due to reduced individual crew recovery opportunities • Caffeine during shift, but no later than 5 h before bedtime • Consider returning to day schedule (sleeping at least 8 h/night) on days off, following a morning nap on first day off from nights • Sleep in on the weekend to make up for sleep loss during the week • Strategic naps (on-the-job) to reduce impact of shortened sleep periods • Consume caffeine just before strategic naps to counteract sleep inertia on waking • Defensive nap in the afternoon before beginning night shift • Self-selected rest breaks to reduce fatiguing impacts of monotonous tasks or highly complex tasks • Supervisory monitoring for signs of fatigue and application of countermeasures
Weekend Closure: 55 h	• Modeling shows same effects as day and night shifts above • Field data suggest increased fatigue among day shift personnel in week following closure • Managers may feel they need to maintain a presence on the job site for as much as possible of the closure weekend; fatigue can accumulate during night shifts	• Consider selective half or full day off after closure to provide recovery opportunity • Anchor (“split”) sleep schedule (nighttime anchor sleep and daytime nap) for managers to obtain 6 to 8 h in two separate sleep periods • Avoid double shifts • Use countermeasures appropriate for shift worked, as described above
Switching Shifts	• Modeling shows same effects as day and night shifts above	• Avoid double shifts • Use countermeasures appropriate for shift worked, as described above
Manager and Designer	• Designers working high production can exceed 80+ h per week	• Reduce high production designer workload through increased staffing and project planning • Same countermeasures as for day shifts, above
Restricted Sleep	• Schedules regularly leading to 6.5 h sleep or less nightly will result in cumulative fatigue • Sleep restricted to 4.5 h or less per night on one or two nights will result in increased fatigue levels, and this short-term sleep loss can affect fatigue long-term • In either case, fatigue level is higher than fatigue levels for standard extended day-shift schedules	• For persons with consistently shortened sleep periods, a daily nap timed to avoid circadian high points (mid-shift or immediately after work) each work day will help maintain fatigue at low levels, and supplement the main sleep period • For individuals with acute fatigue from short-term sleep loss, sleep in on the weekend or take naps when able to make up for sleep loss during the week • Same countermeasures as for day shifts, above

management tools in conjunction with existing safety best practices should enhance safe and efficient project delivery.

Fatigue Risk Management Guide

The materials assembled for this project can best be employed as a “toolbox” for end users such as construction project superintendents, state DOT inspectors, and project planners. To that end, the team has created a separate document as a companion to this report: the *SHRP 2 Project R03 Guide to Identifying and Reducing Workforce Fatigue in Rapid Renewal Projects.*

The *Guide* is for safety managers, persons involved in creating employee work schedules, DOT personnel, and others interested in applying specific and practical recommendations for the management of worker fatigue on highway construction sites.

The *Guide* contains four sections. Chapter 1 presents background and summarizes the main strategies for fatigue management. Chapter 2 describes the basic risk factors of rapid renewal construction schedules and the organizational processes and steps for implementing fatigue risk management. Chapter 3 describes the underlying physiology of human sleep and circadian rhythms, the fundamental mechanisms that contribute to fatigue and work schedule interactions. Chapter 3 also provides a compilation of fatigue countermeasures (discussed in Chapter 4 of this report), incorporating those that are more effective, those that are less effective, and some that are in the preliminary research phase and not ready for widespread implementation. Chapter 4 contains specific shift schedule and work practice guidance for use by managers planning and executing projects. The team has also created two slide presentations, one for general highway workers and one targeted at managers, which can be used to train workers about the dangers and mitigation of fatigue in highway construction projects. These presentations are available at www.trb.org/Main/Blurbs/168766.aspx.

Taken together, these four sections and the slide presentations provide a resource for safety and training managers seeking more detailed technical information concerning worker fatigue and tools for implementing and evaluating components of fatigue risk management.

CHAPTER 7

Conclusions and Recommendations

The Identifying and Reducing Workforce Fatigue in Rapid Renewal Projects project has spanned several years and included a wide range of technical activities, including literature reviews, discussions with stakeholders, field data collection, data analyses, behavioral modeling, outreach, and product and tool development. Taken as a whole, these activities and the resulting research findings have allowed the project team to develop a number of conclusions and recommendations about this important topic. These include the following:

- Fatigue is clearly present in rapid renewal environments and presents considerable safety risks.
- Existing fatigue risk management programs cannot be used in rapid renewal environments; development of a tailored suite of tools and implementation facilitation is required.
- The tools developed in this project have great potential for addressing the fatigue problems identified in this project, but they must be introduced to relevant stakeholders and end users in a clear and supportive manner.
- Outreach should consist of a broad communications effort aimed at scientific and technical audiences as well as industry stakeholder groups.
- Outreach activities should be accompanied by an implementation effort to pilot test the materials developed in this product, evaluate their value and usefulness, and revise them to reflect stakeholder and end-user feedback.

Each of these conclusions and recommendations is discussed in more detail.

Fatigue is clearly present in rapid renewal environments and presents considerable safety risks: The scientific literature review and field research with working highway construction projects demonstrated that rapid renewal scheduling practices can exacerbate worker fatigue through a combination of extended days, night shifts, and weekend closures. These schedules can lead to a reduction in time available for recovery sleep, and fatigue mitigation such as napping during appropriate periods of the work shift does not seem to be practiced.

Existing fatigue risk management programs cannot be used in rapid renewal environments; development of a tailored suite of tools and implementation facilitation is required: The few published analyses of fatigue risk management implementation portray regulated industrial operations, usually within the transport sector (Fourie et al. 2010; Gander et al. 2011). It is likely that the safety functions in regulated industries are more developed than in construction companies. The largest project the team investigated is a $350 million, 3-year program, based on a joint venture between two large companies; this project was served by one full-time safety officer. In smaller firms or projects, the safety function appeared to be served by a foreman on a very part-time basis. Given these fairly minimal staffing levels (and the probable small resources available), it would be a considerable challenge to implement fatigue risk management in the manner typically described in the literature. Available data from process evaluations (Fourie et al. 2010) suggest that even the regulated transport organizations have some difficulty implementing fatigue risk management due to resource limitations, unclear guidance from the regulator, and a tendency to “cut and paste” regulatory guidance templates into a policy document and feed it back to the regulator. The principal risk related to this issue is that fatigue risk management implementation guidance may simply go beyond the capabilities of most contracting firms without external assistance and facilitation.

The tools developed in this project have great potential for addressing the fatigue problems identified in this project, but must be introduced to relevant stakeholders and end users in a clear and supportive manner: The team has developed a suite of tools, including work scheduling aids and work practice guidance, organizational practices, and worker and manager training, that can be used in an integrated approach to fatigue management in rapid renewal highway construction.

The tools were provided to TRB in a form that will facilitate adoption by various organizations, such as industry associations and large or small contracting firms. The team is initiating the process of outreach to foster eventual adoption of the tools and believes that outreach and implementation must be deliberately pursued to ensure successful transition of the products. It is also important that the outreach and implementation activities be initially led by researchers knowledgeable in fatigue risk management, since there is very limited knowledge concerning this topic in the highway construction community. Thus, it would not be realistic or appropriate to simply "hand off" the products of this effort and expect that implementation would be successful. Instead, the team suggests that a follow-on effort be undertaken that would initially use the current research team as "ambassadors" for outreach and implementation, in order to build expertise within the end-user community that will benefit from the work. This endeavor would include various industry group and contracting firm safety managers and construction planners, who would become sufficiently knowledgeable about fatigue risk management to take over and lead a broader, industry-wide implementation.

Outreach could consist of a broad communications effort aimed at scientific and technical audiences as well as industry stakeholder groups. The following outreach activities are examples of what the team would expect to achieve:

Publish Technical Papers

- TRB Human Factors Session (or other highway construction session, as appropriate), January 2013
- *AASHTO* journal
- *Journal of Construction Engineering and Management, Accident Analysis and Prevention; Journal of Occupational Medicine and Environmental Health*

Conduct Committee Briefings

- AASHTO subcommittee on construction
- OSHA Roadway Workzone Safety Alliance

Hold Public Sector Organization Briefings

- FHWA Office of Safety
- Centers for Disease Control and Prevention (CDC)/OSHA

Hold Private Sector Briefings

- AGC
- ARTBA

Involve Worker Organizations

- Laborers' International Union of North America (LIUNA)
- White collar organizations (e.g., for designers and managers)

Consider Additional Outreach

- Webinar(s) that include all of these on the invitation list
- Distribution of print or digital material to selected organizations
- E-mail campaign

Outreach activities should be accompanied by an implementation effort to pilot test the materials developed in this product, evaluate their value and usefulness, and revise them to reflect stakeholder and end-user feedback. Implementation activities would focus more on the specific use and effectiveness of the products generated by the current R03 effort, including training, schedule modeling and guidance, countermeasure guidance, and organizational implementation of aspects of a fatigue risk management system. This activity is much more challenging than outreach, in that it requires motivation and participation by end users on a longer-term basis than simply reading a paper or listening to a webinar or meeting presentation. Under the assumption that the outreach activities will identify such potentially motivated participants, or via other means such as TRB committee contacts, the team envisions the following implementation tasks:

- Identify early adopters of fatigue risk management among large highway construction project new starts.
- Brief state DOT and contractor management during the project design phase, prior to lane closure and work schedule planning.
- Implement workforce training program prior to construction start.
- Implement manager/designer training program at inception of project.
- Gather qualitative (and potentially quantitative) data on perceived value of the R03 products, personnel fatigue, and general fatigue-related safety metrics throughout a defined period.
- Identify lessons learned concerning fatigue awareness, countermeasure implementation, schedule variations, and exceptions.
- Revise R03 products based on implementation experiences and end-user feedback.

A realistic time frame for these activities is in the range of 12 to 18 months, in order to engage the industry group meeting cycle, to conduct individual outreach meetings, and to gather implementation-oriented feedback for potential product modification.

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APPENDIX A

Revised Rapid Renewal Scenario Descriptions

Rapid Renewal Scenario Descriptions

Following are the descriptions of the 13 highway construction rapid renewal projects that were selected as study examples for SHRP 2 Project R03, Identifying and Reducing Workforce Fatigue in Rapid Renewal Projects. These 13 projects provided one means of sampling the various characteristics and factors affecting workforce fatigue among rapid renewal projects. The following descriptions provided the basis for interviews and discussions with involved state DOT, contractor, and construction worker representatives. They also provided the basis for distribution and compilation of surveys addressing specific workforce fatigue factors, conditions, and countermeasures.

Attachment 1 provides a summary of the terms used in developing these scenario descriptions.

Florida Department of Transportation (FDOT) #1: Tampa Airport Interchange Improvement Corridor, FDOT Project Identification Number (PIN) #: 255844-1-52-01, located in the City of Tampa, Hillsborough County.

Overall Project Description

The Tampa Airport Interchanges project is being conducted to improve and renew approximately 3 miles of State Road 60 (Memorial Highway) from I-275 to the Courtney Campbell Parkway interchange, including the extension of 1 mile west onto the Courtney Campbell Parkway (SR-60) and north to the Veterans Expressway (Toll 589). The Spruce Street/SR-60 interchange is being improved to a four-level interchange and the Courtney Campbell/SR-60 interchange will be improved to a three-level directional interchange for the main purpose of eliminating SR-60 traffic signals within the Courtney Campbell interchange and on the causeway at Bayport Drive. The new interchange configuration features the separation of local and express traffic with collector/distributor (C/D) roads and express lanes. This system is also expected to help reduce congestion on the interstate ramps within the area and improve access to Tampa International Airport. With the completion of the project, the Collector Distributors (North and South) of the corridor (Memorial Highway) will carry about 130,000 Average Annual Daily Traffic (AADT 2010) with four lanes in each direction.

The Tampa Airport Interchange Project is a typical megacorridor improvement project with the estimated construction cost of about $214 million and with estimated construction duration of about 5 years (starting Aug 15, 2005, and finishing in Spring 2010).

Project Team Composition

FDOT (District Seven) Construction Engineer was Brian McKishnie (e-mail: Brian.mckishnie@dot.state.fl.us). The prime contractors were a joint venture of Flatiron–Tidewater and Skanska.

Contract Type and Elements

The project is using the typical delivery type of "Design-Bid-Build." The Tampa project adopted various types of incentive bonuses and disincentive penalties, combined with A + B for its relatively complicated phasing construction. For example, the project used three original incentive bonuses with a total amount about $9 million: (1) I/D for A + B: $2,000,000 (200 days @ $10,000/day), (2) a total of $6,350,000 in bonuses for "No-excuse" and several bonus activities, and (3) a total of $650,000 in bonuses for two I/D activities ($50,000/day and $10,000/day). In addition, eight I/D bonuses (total of about $4.2 million) were added by supplemental agreement.

Work Shift Schedules

This project will last approximately 5 years. A majority of construction work was during daytime: The contractor worked virtually every day with the exceptions of Sundays, major holidays, and a few long weekends. In parallel, the contractor performed a substantial amount of work with lane closures during approximately 1,500 nights. Night construction was used primarily to keep the existing travel lanes open during the day to allow maximum traffic flow during peak driving hours. Lane closure hours vary depending on the traffic control needed, but the general window is between 8:30 p.m. and 5:30 a.m. for these operations.

FDOT #2: SR-50 Corridor Improvement Project, FDOT PIN #: 248329-4, located between the Town of Oakland and the City of Clermont (in the rural area), Western Orange and Eastern Lake Counties.

Overall Project Description

The SR-50 corridor improvement project is being conducted to reconstruct and widen approximately 5.5 miles of rural four-lane highway, to a six-lane urban highway in Western Orange and Eastern Lake Counties. The project also includes the provision of a raised concrete median, signalization improvements at five intersections, a closed storm water system with six ponds, and signing and pavement markings. The AADT of the corridor is 45,000. The SR-50 corridor improvement project started on March 19, 2009.

One of the most challenging aspects of this project is the requirement to relocate approximately 13 utility facilities (with different owners). These relocations are in some degree dependent on each other in various ways. Utility work triggered by a roadway project typically provides no additional revenue to the utility owner. This lack of additional revenue generation can cause the utility owner to place roadway relocation work low on their priority list. Various meetings and interactions are required to keep utility owners motivated to perform work on the project, so as to not to delay the roadway work.

Project Team Composition

Project's Resident Engineer in FDOT (District 5) is John Hatfield. The contractor for the project is Prince Contracting, LLC. Representing FDOT through the provision of Construction, Engineering, and Inspection (CEI) services is the firm DRMP, Inc., as outsourcing.

Contract Type and Elements

The SR-50 corridor improvement project is a Design-Bid-Build project, using the contract type of "A + B" with 1,000 contract calendar days. Prince Contracting, the successful bidder, submitted a bid of about $18 million (although the project budget allocated was about $30 million).

The FDOT desires to expedite construction to minimize inconvenience to the traveling public through reduced construction time. A bonus amount of $250,000 will be paid if all work from station 446+00 to 456+50 is complete, with the exception of friction course and final pavement markings, and open to traffic by August 23, 2011. In addition to the above bonus, and for the same reasons, a project "incentive/disincentive completion date" of August 23, 2011, is in the contract, with $9,000 per day incentive/disincentive set, not to exceed amounts in both directions.

Work Shift Schedules

The work schedules of personnel on the project vary, in both work hour and work days, based on the type of construction taking place. The work schedule of the contractor dictates, to some extent the work hours of the Project Administrator, Sr. Inspectors, and Inspectors. The "standard" work hours of the team are from 7:30 a.m. till 4:30 p.m., Monday through Friday. One day per week, on average, an 8:00 p.m. through 6:00 a.m. shift may be required, while a Saturday work day averages twice a month. The contractor has the ability to work 7 days per week. A constraint of the contract is no lane closures can take place during the time from 5:00 a.m. through 8:00 p.m., which requires night work on certain contractor activities.

Specific Workforce Fatigue Factors

The current and expected continuation of variation in both work days and work hours, the temperature increases which have started to take place in early April, the increase in rain, along with its associated humidity, will all be workforce fatigue factors to contend with. The contractor's ability to change its work schedule on a daily basis contributes to the uncertainty of all team member schedules, increasing the challenge of scheduling effective rest periods and introducing additional overall stress.

One unique fatigue issue for the project workforce is lengthy commute time for the inspection team (CEI). For example, Rickey Langley, Sr. Project Engineer, lives approximately 45 miles from the project office, and his commute time is about 50 min each way. Karle Maye, Project Engineer, lives approximately 110 miles from the project office, and his commute time is in excess 2 h each way. Tony Foti, Office Engineer, lives approximately 40 miles from the project office; his commute time is more than 1 h each way (about ⅓ of Mr. Foti's time is spent on this project, and the remainder of his time is in this project office, on other roadway projects). Timothy Bauer, Senior Inspector, lives approximately 70 miles from the project's office, and his commute time is more than 1 h and 15 min each way.

Specific Workforce Fatigue Countermeasures Employed

DRMP allows their salaried team members to offset hours the day following an extended workday. As an example, if a project engineer work 8:00 a.m. till 10:00 p.m. on Monday, they could report to work "late" the next work day. Prince Contracting provides their field forces with water coolers and iced water, as well as water bottles that can be filled from the coolers.

New York State DOT (NYSDOT) #1: Route 9P Bridge Replacement Project (NYSDOT #: 1247.08), located in the city of Saratoga Springs, Saratoga County.

Overall Project Description

The purpose of this project is to completely replace the deteriorated bridge over the Saratoga Lake outlet from steel truss structures, which were built in the 1930s, with new bridge decks with steel girder structures.

The original construction plan (Alternative 3E) was to replace the old bridge after a temporary parallel bridge was built first for the traffic detour. The expected cost of this plan was $17.6 million. However, NYSDOT has concluded this project needs to advance to construction as quickly as possible, as the most recent annual bridge inspection showed the rate of deterioration of major bridge structure components had increased and that emergency repairs were needed in order to keep the bridge open. Thereafter, a construction alternative (Alternative 5A) was selected to replace the bridge on existing alignment with full bridge closures, which needs vehicular traffic detoured off-site (about maximum 16 miles via state routes). This alternative (estimated cost of about $10.7 million) will save construction cost (about $7 million) and reduce construction duration, compared with the Alternative 3E plan.

The bridge has two lanes in total (one lane for each direction) and carries daily traffic of about 6,500 vehicles. The duration of the construction is from March 2010 for preparation works through Aug. 2011 for finish works. The bridge full closure is scheduled for about 9 months (from Sept. 7, 2010, through May 27, 2011) to accommodate the leisure traffic in summer.

Project Team Composition

The Project Resident Engineer is Robert Remmers, the NYSDOT Project Manager is John V. Nolan, the NYSDOT inspector is Sam Cook, and the Prime Contractor is Kubricky Construction.

Contract Type and Elements

The project is using conventional delivery method of Design-Bid-Build with an A + B contract, not adopting any contract incentives or disincentives.

NYSDOT #2: I-287 Corridor Improvement Project (Phase III), NYSDOT Project #: 8729.52, located in Westchester County.

Overall Project Description

The I-287 (Cross Westchester Expressway) Reconstruction Project was designed to improve mobility and safety for motorists and to reduce road-related noise for area residents. The Cross Westchester Expressway is the busiest highway in the Hudson Valley region, carrying about 140,000 vehicles a day with three travel lanes for each direction. Although the road is serving far more cars than it was designed to carry, particularly at rush hour, the project is not intended to increase its capacity. Project highlights of the 1.8-mile construction area between Exits 6 and 8 include: (1) rehabilitation of I-287 roadway, (2) addition of an eastbound auxiliary lane, (3) relocation of Exit 7 further east, (4) construction of a westbound frontage road, (5) replacement of nine bridges, (6) rehabilitation of one bridge (Ramp I), (7) construction of one new bridge (Ramp I), (8) removal of one bridge, and (9) installation of noise-barrier and retaining walls along portions of both sides of I-287.

The I-287 corridor improvement project was implemented with three phases ($500 million in total). During the Phase 1 project (2001 to 2004), I-287 was realigned so that traffic coming off the Tappan Zee Bridge into Westchester could continue on the interstate rather than being automatically channeled onto the New York Thruway. The Phase 2 project (2002 to 2006) involved installing sound barriers and repairing and adding an auxiliary lane at Knollwood Road near Exit 4. The last phase (Phase III, 2006 to 2010) was expected to cost about $160 million. The cost includes replacing nine bridges, constructing a new one, and demolishing another. Five of the nine bridges being replaced are in the North Broadway neighborhood in White Plains. Ongoing work has included work on several bridges, making acceleration and deceleration lanes longer, erecting noise barriers, replacing railings and resurfacing the roadway. The I-287 Reconstruction Project (Phase 3) began in August 2006.

As the highway reconstruction is within the city limits of White Plains, the NYSDOT worries about the local vehicle and pedestrian traffic as well as the interstate (I-287) traffic. Some of the work will involve blasting, which may require traffic to be halted. Traffic may also be slowed by alternate traffic patterns. No lanes will be closed during rush hours. A goal is to maintain traffic capacity throughout the life of the job. Among the primary concerns of residents are the blasting, traffic disruptions that could send more cars through the neighborhood, and work being done during the evening with overnight shifts from 10:00 p.m. to 6:00 a.m.

Project Team Composition

The NYSDOT Project Manager is Kerril Hynes, Outsourced Project Inspector is Bozwell Engineering, and the Prime Contractor is a joint venture of Yonkers Contracting and Dragados.

Contract Type and Elements

As an A + B contact, the actual awarded contract amount of the I-287 project (Phase 3) was about $142 million for the A portion (Cost), and about $13 million as the B portion (Time). The schedule baseline was to allow 900 maximum working days with 20,000 incentives bonus per day up to a maximum of 90 days.

Work Shift Schedules

The contractors' typical work schedule was a combination of daytime (8 to 10 h) and nighttime (8 to 10 h) shifts.

Specific Workforce Fatigue Factors

Only expected when night shift crew cannot work at nighttime due to lane restrictions and works day shift after night shift. For example, if the contractor crew works Monday, Tuesday, and Wednesday nights (8:00 p.m. to 6:00 a.m.), then works Thursday and Friday (4:00 p.m. to midnight).

Illinois Department of Transportation (IDOT) #1: I-290 Resurfacing Project, IDOT #: 60K10, located in the cities of Maywood, Forest Park, and Oak Park in Cook and DuPage Counties.

Overall Project Description

Starting in Spring 2010, the IDOT will begin to resurface approximately 27 miles of I-290 (Eisenhower Expressway) with the goal of restoring a smooth, safe ride for the motoring public. The project limits are in Cook and DuPage Counties extending from: (1) Thorndale Avenue to Interstate 90/94 (Circle Interchange); and (2) Interstate 355 from Army Trail Road to I-290. I-290 was last resurfaced 11 years ago. The general scope of work is to mill and resurface along I-290. In addition to entrance and exit ramp resurfacing, work will be done on bridge structures. Bridge work will include bridge deck and approach pavement patching, barrier wall repair, and joint repair. The I-290 project repairs 37 bridges along the project area, including entrance and exit ramps. Project start date is April 1, 2010, and the resurfacing completion date is October 31, 2010, as fast-track construction.

I-290 generally consists of three to four lanes in each direction with variable width shoulders. Construction will take place in both directions simultaneously inbound and outbound and will use permanent lane closures and temporary nighttime lane closures. The estimated cost for this 1-year project is $95 million.

Project Team Composition

The project Resident Engineer is James Patton. The prime contractor is Plote Construction, Inc., joint ventured with Central Blacktop and K-Five Corp.

Contract Type and Elements

The project delivery type is a variation of Design-Bid-Build, as design is outsourcing to Consultant with IDOT oversight and stamp as Phase II of the project, then let other contractors build it as Phase III. The contract specifies $7,500 liquidated damages penalty for failure to complete contract on time, per calendar day or portion thereof of overrun in contract time.

Milling and resurfacing will be utilizing temporary night lane closures. Permanent lane closures will be required during bridge repairs, which will reduce one lane along Interstate 290 in each direction.

The I-290 renewal project is performed with six contracts mainly due to its size and complexity as well as the urgent need for early completion:

(1) Contract 60G51: I-290 from Thorndale Avenue to east of Church Road, and I-355 from Army Trail Road to I-290. Total length is approximately 8.6 miles with the main scope of pavement renewal (resurfacing and rehabilitation) of mainline as well as ramps and interchanges and repairs of 16 bridge structures.
(2) Contract 60I57: I-290 from east of Church Road to I-88. The total length is approximately 4.3 miles with the main scope of repairs of 12 bridge structures.
(3) Contract 60K12: I-290 from I-88 to 9th Avenue. Total length is approximately 3.39 miles with the main scope of pavement renewal and six bridge structures repair.
(4) Contract 60K10: I-290 from 9th Avenue to Austin Avenue. Total length is approximately 3.86 miles with the main scope of pavement renewal and repairs of bridge structure.

(5) Contract 60K13: I-290 from Austin Avenue to Sacramento Boulevard. Total length is approximately 3.79 miles with the main scope of pavement renewal and repairs of two bridge structures.
(6) Contract 60K11: I-290 from Sacramento Boulevard to I-90/94 (Circle Interchange).

Illinois DOT #2: I-80 Bridge Repairs Project (IDOT #: 64F31), on I-80 over the Mississippi River located in the City of Moline, Rock Island County.

Overall Project Description

The I-80 bridge spanning the Mississippi River and connecting LeClaire, Iowa, and the Moline area of western Illinois will see large-scale repairs in Spring 2010. Civil Constructors, of Moline and Freeport, Ill., will repair the end sections of floor beams that mount to the outside of the 43-year-old bridge's main girders and support the outside lanes of the bridge deck. The bridge is a key river crossing, carrying more than 30,000 vehicles per day.

Work on the 43-year-old bridge originally started in Spring 2009, with workers repairing its deck. During the course of that work, inspectors noticed corrosion in some of the structural components called floor beams, whose cantilevered ends stick out from the side of the bridge and support the outside two lanes of the bridge deck. They also found a crack in one floor beam. So the IDOT closed the bridge's two outside lanes to prevent traffic from further damaging the bridge before it could be repaired. John Wegmeyer, project implementation engineer for IDOT, explained that the damage is at expansion relief joints and affects only the cantilevered ends of the floor beams, not the center sections between the girders.

Although the section of bridge where the floor beams need to be repaired sits about 75 ft above the river, IDOT's Wegmeyer and the contractor both say that the repairs can be made from the bridge itself, without using a barge-mounted crane in the river.

Project Team Composition

In November 2009, Helm Group Civil Constructors of Moline and Freeport, Ill., submitted the lowest bid, $10.3 million, to repair the damaged end sections of floor beams and portions of eight stringers (small I-beams that lay perpendicularly across the tops of the floor beams) and to repave the associated sections of bridge deck. The IDOT Project Resident Engineer is Brian Holliday (Phone: 309-523-2078).

Contract Type and Elements

Because the bridge is a vital link between Illinois and Iowa, the contract offers incentives totaling $1.4 million if the contractor meets or beats milestones that include getting two-way traffic flowing early before the summer travel season starts. It also contains penalties of up $20,000 per day for missing milestones.

The nature of this project is such that this roadway cannot be safely and efficiently used until all roadway work is essentially complete. The Incentive Payment shall be paid at the rate of $20,000 per calendar day for each day of completion prior to July 15, 2010. The maximum payment under this incentive plan will be limited to 30 calendar days.

Failure to Complete the Work on Time: Should the contractor fail to complete the work on or before the specified date of completion, or within such extended time allowed by IDOT, the contractor shall be liable to the Department in the amount of $20,000, not as a penalty but as liquidated and ascertained damages for each calendar day or portion thereof beyond the date of completion or extended time as may be allowed. Such damages may be deducted by the Department from any monies due the contractor.

The Incentive Payment for Stage 2 shall be paid at the rate of $13,000 per calendar day for each day of completion prior to November 1, 2010. The maximum payment under this incentive plan will be limited to 30 calendar days.

Work Shift Schedules

The contractor will be working multiple crews and double shifts for some operations to make repairs as quickly as possible. The I-80 Mississippi River Bridge will be closed for all eastbound traffic on Monday, April 5, 2010. Eastbound I-80 traffic to Illinois will be routed to I-280. The structure repairs to the eastbound half of the bridge are scheduled to be completed by early July 2010. At that time, one lane of traffic in each direction will be placed on the eastbound half of the bridge while the two westbound lanes are repaired.

Washington State DOT (WSDOT) #1: I-5 Seattle Reconstruction Project, WSDOT #: C6886, located in City of Seattle, King County.

Overall Project Description

I-5 Seattle corridor is the main north-south interstate freeway in Washington State. It currently carries 280,000 average daily traffic, including 12,000 trucks (carrying $200 million in cargo). Congestion in and around downtown Seattle primarily occurs during the morning and evening peak periods due to high traffic volumes. The original concrete pavement was deteriorating to the point where it needed to be removed and replaced to preserve the freeway and provide a safer, smoother ride for drivers.

The I-5 Reconstruction Projects preserved the most important route in Washington State and improved traffic flow and safety by (1) removing the original deteriorating concrete and replacing it with new pavement reinforced with dowel bars, which allowed WSDOT to "Get In, Get Out and Stay Out" for 40 years, and (2) addressing long-standing traffic chokepoints with strategic operational improvements such as closely spaced ramps, ramps on the left side, and reduced shoulders.

The project was awarded for $3,948,000 and was designed to be completed in four 55-h weekend closures (10:00 p.m. Friday to 5:00 a.m. Monday).

Major work consisted of the following:

- Demolish and remove approximately 6,500 yd^3 (4,970 m^3) of material consisting of
  - ○ 230 mm (9 in.) of existing concrete pavement and Hot Mix Asphalt (HMA) overlay; and
  - ○ Approximately 180 mm (7 in.) of aggregate base course.
- Place new Portland Cement Concrete (PCC) pavement consisting of
  - ○ 75 mm (3 in.) of HMA base material (about 2,270 tonnes (2,500 tons))
  - ○ 33 mm (13 in.) of doweled jointed plain concrete pavement (about 4,312 m^3 or 5,640 yd^3)

Project Team Composition

The WSDOT NW Region Project Engineer in the Seattle area was Julia Mizuhata (425-225-8763; mizuhaj@wsdot.wa.gov). Personnel from other NW Region offices provided assistance during the 55-h weekend closures, in addition to the Washington State Patrol.

The prime contractor was Gary Merlino Construction Company, Inc., of Seattle, Washington, along with several subcontractors.

Contract Type and Elements

In an effort to reduce traffic impacts, WSDOT offered a $100,000 incentive for completing the work in three weekend closures. Weather and event considerations eventually resulted in construction taking place in the following four 55-h weekend closure stages:

- Stage 1: April 22 to 25, 2005
- Stage 2: June 17 to 20, 2005
- Stage 3: June 24 to 27, 2005
- Stage 4: July 15 to 18, 2005

Work Shift Schedules

The contractor used non-stop (typically three shifts per day) construction during the 55-h extended weekend closures for the majority of the I-5 pavement reconstruction project works.

Specific Workforce Fatigue Factors

Work performed during the 55-h extended weekend closures were on an overtime basis following a 40-h work week on the reconstruction project or other projects. The prime contractor brought in individual crews based on major work activity such as demolition, excavation, grading, asphalt paving, and concrete paving. These crews typically worked non-stop until completion of the activity. WSDOT crews were on non-stop, 12-h shifts. The effort to meet the 55-h time frame was intensive, since the traveled lanes and ramps needed to be re-opened to traffic by Monday morning.

Specific Workforce Fatigue Countermeasures Employed

Efforts were made by the State when possible to keep employees that were on a day shift retained on a day shift during the 55-h weekend (6:00 a.m. to 6:00 p.m.), and employees on a nighttime shift were kept on nights (6:00 p.m. to 6:00 a.m.).

WSDOT #2: I-90 Homer Hadley Bridge Expansion–joint replacements, WSDOT #: C7579, located in Seattle, King County.

Overall Project Description

The I-90 project replaced four expansion joints: two on the I-90 east and west approaches to the floating bridge on the center roadway and two at the approaches of the westbound roadway. The primary goals of this project were to replace the failing expansion joints to ensure traffic safety and preserve the bridge structure.

Overall project duration is about 20 months (410 working days), starting in April 2009 and finishing in November 2010.

Project Cost is estimated at $52 million (Engineer's Estimate was $68 million).

The AADT along this stretch of highway is approximately 200,000 (both directions), and the truck percentage is about 10%.

The total number of lanes on this portion of I-90 is two lanes on center portion and three lanes westbound.

Project Team Composition

The project client is WSDOT NW Region (Seattle area). The Project Engineer is Hien Trinh.

The prime contractor is General Construction Company (owned by Kiewit), which has a number of subcontractors.

Contract Type and Elements

This is a Design-Bid-Build contract. The project consisted of two distinct phases of work operations. Phase 1 replaces the expansion joints on the center roadway during May 2009. Phase 2 replaces the expansion joints on the westbound roadway during July 2009. During Phase 1 the center roadway was completely closed to traffic. During Phase 2 the westbound roadway was completely closed to traffic and the center roadway then had to accommodate all westbound traffic during this phase of work. Incentives included a total original budget of $560,000 to reduce the number of calendar days (for work), thus reducing high traffic impacts, with $40,000 per day during Phase 1 and $80,000 per day during Phase 2 incentive for each day of reduction up to 4 days per phase not to exceed the total incentive amount. Before construction of the westbound roadway (Phase 2), a contract change order was negotiated and executed offering additional incentive amounts of $38,000 per day up to $190,000 to further reduce work duration and high traffic impacts.

Work Shift Schedules

Both Phases 1 and 2 were contracted for 24 × 7 work. The contractor initially scheduled two 10-h. shifts per day, but on most days work was accomplished around the clock.

The project requires various types of construction operations by individual agencies (WSDOT engineers and inspectors and Washington State Patrol), contractors (management, construction workers, and subcontractor workforces) and a local agency (Mercer Island police to aid local traffic control on city streets).

Specific Workforce Fatigue Factors

The construction is apparently being conducted with some workers performing other ongoing work, with day-shift workers and even some night-shift workers also working on weekends.

The workload of the WSDOT workers is also intensive during construction. For example, WSDOT field staff (engineers and inspectors) and Washington State Patrol are continuously present on-site with the contractors in two or three work shifts during both major phases of 24 × 7 work operations.

WSDOT #3: SR-520 Eastside Transit and HOV Project, located between Medina and Bellevue, King County.

Overall Project Description

Washington State Route 520 (SR-520) was built in the 1960s and is a busy regional corridor that connects key Eastside communities, including Bellevue, Kirkland, and Redmond in Washington State. Population and employment have steadily grown in these communities over the past several years, leading to increased traffic and transit demand. This rise in congestion has led to frustrating commutes and unreliable transit travel times. In 2009, the Washington State Legislature set a program budget of $4.65 billion for the SR-520 Bridge Replacement and high-occupancy vehicle (HOV) program to implement the following WSDOT projects: (1) Eastside Transit and HOV Project; (2) Bridge Replacement and HOV Project; (3) Pontoon Construction Project; and (4) Lake Washington Congestion Management Project.

Beginning in the spring of 2011, drivers on SR-520 will be exposed to major construction work between Medina and 108th Avenue, NE, as the SR-520 Eastside Transit and HOV Project (so-called "SR-520 Project," as described in this scenario summary) gets under way. The 3-year project starts construction in April 2011 and is scheduled to open to traffic in December 2013. It costs about $306 million to improve transit facilities and provide community and environmental features.

The SR-520 project will complete and improve the 8.8-mile HOV system on SR-520 from Evergreen Point Road to the SR-202 interchange. The end result of the SR-520 project will provide the improved six-lane corridor, including two general-purpose lanes and one transit/HOV lane in each direction. The SR-520 project will provide more reliable transit service and mobility improvements (especially HOV travel time), interchanges improvement and safety, and environmental and community enhancements. Funding for the project was allocated by the Washington State Legislature using a combination of state and federal funding and future SR-520 toll revenue. Tolling is scheduled to begin in Spring 2011 and toll rates will be set by the state Transportation Commission.

The main scope of the SR-520 project includes the following:

- Widening the corridor and constructing new transit and carpool lanes, shoulders, and other facilities along 2.5 miles of SR-520 from west of Evergreen Point Road to east of 108th Avenue, NE, in Bellevue.
- Constructing newly aligned general-purpose ramps and direct-access ramps for buses and carpools at 108th Avenue, NE.
- Constructing a regional bicycle and pedestrian path, noise walls, storm water treatment, and detention facilities.

As a scale of construction materials for the SR-520 project, the contractor's crews will use approximately 65,000 yd^3 of concrete; 10.5 million lb of rebar to build bridges and strengthen concrete; 234,000 tons of asphalt to pave SR-20 and parts of local streets; and 450,000 yd^3 of earthwork.

Project Team Composition

Eastside Corridor Constructors (ECC)—a joint venture of Granite Construction Company, PCL Construction Services, HW Lochner, David Evans & Associates, Perteet, and others—is the contractor for the SR-520 project for WSDOT. The project teams contact information follows:

- WSDOT SR-520 program contact: E-mail: SR520bridge@wsdot.wa.gov; Phone: 206-770-3500
- Construction contact: E-mail: dan.galvin@gcinc.com; Phone: 425-998-5200

Contract Type and Elements

This is a Design-Build contract, using Best Value Determination in the bid evaluation, by combining design and construction in one contract at a fixed price.

Work Shift Schedules

The SR-520 project includes a combination of (1) Extended Day Work, (2) Weekend Work (non-stop with multi-shift), and (3) Night Work, depending on the specific construction element and location. Drivers and transit riders can expect traffic shifts, lane and ramp closures (during non-peak hours), and up to 20 full highway closures over the next 3 years. In particular, the first complete closure of SR-520 is scheduled for a weekend in June 2011 to remove a pedestrian bridge west of 84th Avenue, NE. Smarter Highways signs on SR-520 automatically alert drivers to changing road conditions, including lane closures for construction.

Specific Workforce Fatigue Factors

The project includes daytime construction, nighttime construction, and a small amount of extended (non-stop) weekend construction. Daytime and nighttime shift workers might work on extended weekend construction work. The weekend construction work is intense, involving multiple operations occurring close to one another, requiring precision planning and logistics to maintain safety, complete the work, and open lanes to traffic within the allowable closure limits.

Utah Department of Transportation (UDOT) #1: I-15 Corridor Expansion (CORE), UDOT #: MP-I15-6(178)245, located in Salt Lake City, Salt Lake City County.

Overall Project Description

The I-15 Corridor Expansion (CORE) is needed to alleviate traffic congestion, support economic development, increase safety, and accommodate population growth. I-15 CORE is an important investment to restore aging infrastructure, address long-term transportation needs, and improve the movement of goods and services throughout the state. I-15 CORE project is one of the largest corridor improvement projects for the UDOT with the basic scope of widening and rebuilding 24 miles of I-15 in Utah County.

I-15 CORE expands the freeway by two lanes in both directions from Lehi Main Street to Spanish Fork Main Street; extends the express lane from University Parkway in Orem to Spanish Fork; rebuilds and reconfigures 10 freeway interchanges; and replaces and restores 55 bridges. It also provides additional improvements that will meet or exceed travel demands through the year 2030, including using 40-year concrete pavement along the entire corridor.

UDOT is employing innovation and working around the clock with an aggressive construction timeline to complete the project 2 years earlier than originally scheduled. While efforts will be made to minimize inconvenience, there will be periods of significant delays. The schedule milestones are as follows. Design and Pre-construction, which began in January 2010, and construction starts in Spring 2010. The schedule target for the completion of the project is (1) June 2012 for Phase I (Lehi Main St. to Pleasant Grove) and (2) December 2012 for Phase 2 (Pleasant Grove to Spanish Fork).

As a mega-corridor improvement project, UDOT's estimate for the Total Project Cost $1.725 billion: is a sum of approximately $600 million for ROW and for an approximate $1.1 billion of construction cost.

Traffic on I-15 varies along the Corridor with currently approximately 40,000 AADT with typically three lanes in each direction.

Project Team Composition

Todd Jensen is the Deputy Project Director (Tel: 801-341-6407; E-mail: toddjensen@utah.gov). UDOT has selected Provo River Constructors (PRC), a consortium of expert local, regional, and national contractors and engineers to design and build I-15 CORE. In a competitive bidding process, PRC proposed the greatest value solution within the fixed budget with some innovative and creative strategies, while upholding UDOT's quality, mobility, and safety standards.

Contract Type and Elements

I-15 CORE is a Design-Build project, which means that the design process is ongoing during the initial stages of construction. As a part of this Design-Build process, the schedule for specific aspects of the project and working in particular areas is still being established. The project does not implement any incentives or disincentives for the contractor's schedule performance.

UDOT #2: Replacement of the 4500 South Bridge, UDOT #: F-I215(126)13, located on SR-266 over I-215 in Salt Lake City, Salt Lake City County.

Overall Project Description

This project used accelerated bridge construction (ABC) techniques to remove and replace the 4500 South Bridge on State Route 266 over I-215 in Salt Lake City in 2008. As part of a national initiative sponsored by the Federal Highway Administration under the Highways for LIFE (Long-lasting, Innovative, Fast construction, and Efficient) program, UDOT was awarded a $1 million grant to demonstrate the use of proven, innovative technologies for accelerated bridge removal and replacement.

The 4500 South Bridge on SR-266 in Salt Lake City, Utah, was built in 1971 to cross I-215 and to serve as an important access point for local businesses and residents. The bridge was in very poor condition, with delaminated, distressed concrete columns, pier caps, girders, and decks as well as badly exposed and corroded reinforcing steel. After exploring alternatives and evaluating project and user costs, UDOT selected innovative ABC and project delivery strategies to remove and replace the bridge.

Dramatic reduction in user costs and increase in motorist and worker safety and user satisfaction was achieved through the use of a revolutionary construction engineering aid: self-propelled modular transporter (SPMT). The innovations employed on the project represented many firsts for UDOT, including the use of an SPMT and several of the substructure elements. The biggest innovation was the removal and replacement of the bridge using an SPMT. The entire operation (removal and installation of the main bridge structures) took a mere 53 h over just one weekend and has significantly raised customers' future expectations of UDOT on highway project delivery methods and time frames. The entire removal took about 4 h on Saturday, October 26, 2007. After moving both parts of the existing superstructure to the demolition area, work on rubblizing the existing columns and bent caps began over I-215. The remaining time on Saturday was spent removing the rubblized materials and preparing the abutments for placement of the new superstructure. On Sunday, October 28, the SPMT moved the new single-span superstructure to its final destination supported by the newly built abutments. The entire superstructure was pre-fabricated in the gore area, next to the existing bridge. The new 172-ft-long (52.4-m-long) superstructure, which weighed about 16,000 tons (14,514 metric tons), was the longest bridge ever moved by an SPMT in the United States. I-215 reopened to traffic on Monday, October 29, at 1:00 a.m. The 4500 South Bridge reopened to traffic about 10 days later, after the precast approach slabs and bridge detail work were completed.

The project was delivered on a tight schedule as a Design-Build project for innovative fast-track construction and was estimated to have been completed approximately 12 months earlier than the traditional (Design-Bid-Build) approach to bridge construction. UDOT estimated that under conventional construction, which would have employed partial lane closures, the user impact would have been felt for 120 days over a 4- to 6-month period. An effective public information campaign involved both outreach and communication.

The benefits and costs of this innovative project approach were compared with those of a project of similar size and scope with a more traditional delivery approach. The economic analysis revealed that UDOT's approach, using the accelerated bridge construction technique for the 4500 South Bridge over I-215, achieved a cost savings of about $3.24 million or 36% over conventional construction practices. A significant amount of the cost savings was from reduced delay costs.

Contract cost of the bridge replacement project was $8.7 million and construction was from June 2007 to November 2007.

Project Team Composition

The project manager was Lisa Wilson. As a Design-Build project, the prime Contractor was Ralph Wadsworth.

Contract Type and Elements

The project implemented an innovative contracting method, Construction Management/General Contracting (CM/GC) services, that involves early partnering between owner, designer, and contractor in order to streamline the project delivery process.

Work Shift Schedules

The basic workforce schedule was daytime shifts except for one weekend of the bridge replacement. The bridge was closed for about 10 days to local traffic. The main works for the bridge replacement required non-stop (around the clock) construction operations with different crews working two to three shifts per day over the 55-h weekend. The traffic on the bridge as well the freeway mainline underneath was fully closed during that weekend.

California Department of Transportation (Caltrans) #1: I-15 Ontario Rehabilitation Project, Caltrans #: 08-472211, located in the city of Ontario, San Bernardino County.

Overall Project Description

This is a mega-highway renewal project (so-called "Rapid-Rehab" in California) to rebuild an approximately 5-mile stretch of long-life concrete pavement on an urban corridor.

The project includes various types of innovative construction, such as "pre-cast concrete" and "rapid-strength concrete." The I-15 Ontario project is a typical example of freeway pavement renewal in an urban network in California with high traffic volumes through the work-zone (WZ). The primary goal of this project is to provide long-lasting pavement (30+ years), to induce minimum work-zone impact on road users and to achieve maximum construction productivity. This project is a recipient of a $5 million FHWA Highways for LIFE grant, a program to encourage these goals.

The project includes multiple stages of work. The first stage involved widening bridges and paving the median. The second stage shifts southbound traffic toward the median while pavement in the outer southbound lanes is rehabilitated. After some minor adjustments in the median, the next stage shifts the northbound lanes toward the median in a similar manner to rehabilitate the outer northbound lanes. The final stage of work places a permanent concrete barrier along the median.

Overall project duration is about 20 months (410 working days), starting in April 2009 and finishing in November 2010.

Project Cost is estimated at $52 million (Engineer's Estimate was $68 million).

The AADT along this stretch of highway is approximately 200,000 (both directions). Truck percentage is about 10%.

The total number of lanes on this portion of I-15 varies between four and five lanes per direction, with between two and three lanes being rebuilt in each direction.

Project Team Composition

The project client is Caltrans, District 8 (San Bernardino and Riverside counties). The project team includes Jonathan den Hartog (Project Engineer), Siong Yap (Construction Engineer), Nahro Saoud (Resident Engineer), Juan Lizarde (Project Manager), and FHWA representatives from their Highways for LIFE program. The primary contractor is Security Paving Company (Sun Valley, Calif.), which has a number of subcontractors.

Contract Type and Elements

This is a Design-Bid-Build contract. The contract has Incentives/Disincentives clauses that have a total budgeted amount of $900,000 dollars of incentive. The incentive is used to increase the contractor's construction schedule awareness to become innovative and to increase productivity efficiency so that the number of 55-h weekend closures is reduced. The incentive bonus of $150,000 is awarded for each weekend closure eliminated or reduced below the minimum expected 27 closures for the extended 55-h weekend closures. The total maximum incentive is limited up to $900,000 for the contract.

Work-Shift Schedules

The project includes a combination of (1) extended day work, (2) weekend work (non-stop with multishift), and (3) night work, depending on the specific project element and location. The project's construction staging plans require different types of construction strategies (primarily work hours), such as conventional day-shift continuous work, 55-h extended weekend work, and traditional nighttime work, as determined based on the consideration of work locations and lane closure schemes.

The project requires various types of construction operations by individual agencies [Caltrans engineers and inspectors and California Highway Patrol (CHP)] and the contractors (management, construction workers, and subcontractor workforces). For example, about 27 repeated weekend closures with nonstop construction are required, primarily for interchange ramps and freeway-to-freeway (I-10 to I-15) connector areas, with full traffic closure providing better contractor access. The preconstruction analysis indicated that 27 extended weekend construction work closures would allow the completion of work equivalent to about 3 to 4 years of repeated nighttime work closures.

The southern area of the project boundary is designed for approximately 100 nighttime shifts using rapid-strength concrete (4-h curing-time concrete mix) because of limited space for traffic detours. Other mainline areas are designed for conventional daytime work behind concrete barriers with traffic detoured to temporarily widened median areas.

Specific Workforce Fatigue Factors

The project includes daytime work, nighttime work, and multiple extended (55-h) weekend closures. Day- and night-shift workers also work on the extended weekends. The weekend construction work is intensive, involving multiple operations occurring close to one another, requiring precision planning and logistics efforts to maintain safety, complete the work, and open lanes to traffic within the allowable closure limits. Workers often work longer (more than 8 h) shifts in order to complete the work.

Extensive efforts are required on the part of Caltrans field staff (engineers and inspectors) to monitor the construction and on the part of the CHP to assist in managing traffic. They often work two or three work shifts during these weekend closures to provide sufficient coverage. The extended weekend closures are often repeated multiple weekends in a row, with the only exceptions being holiday weekends and weekends where inclement weather is forecasted.

Specific Workforce Fatigue Countermeasures Employed

A skeleton crew is used on 55-h weekend work.

Whenever possible, staff are limited to one 10-h shift per 55-h weekend closure. Staff have been borrowed from other units on an as-needed basis. All staff have been advised to bring to their supervisor's attention any issues related to the long work hours.

Superb planning, scheduling, and organization is a must and key to success. The 55-h weekend closures ultimately increase productivity, safety, and reduce contract time to deliver the project.

Time savings achieved by using extended weekend closures (versus all nighttime closures) was estimated to be almost 3 years, and of course, results in a much better product than nighttime closures would have achieved. In other words, the project is taking a little more than 2 years to complete instead of 5 years, due to the use of extended weekend closures, median paving, and shifting traffic during construction.

Caltrans #2: I-680 Walnut Creek Rehabilitation Project, Caltrans #: 04-447001, located in the cities of Walnut Creek and San Ramon, Alameda County and Contra Costa County.

Overall Project Description

This is the largest highway renewal project in northern California to resurface or rebuild an approximately 12.6-mile stretch of existing concrete pavement on an urban corridor. In terms of the project scope, about half of the project boundary is designed for concrete pavement rehabilitation (mainly with pre-cast panels), whereas the remaining half of the project area is designed for Asphalt Concrete (AC) overlay surfacing (so-called Crack-Seat and AC overlay).

Overall project duration is about 500 working days (about 25 months over three construction seasons), expected to start in Fall 2010 (the bid announcement is scheduled in summer 2010).

Project cost is estimated at $70 million (Engineer's Estimate).

The Average AADT along this stretch of highway is approximately 180,000 (in both directions). Truck percentage is about 6%.

The total number of lanes on this portion of I-680 varies between four and five lanes per direction (including one HOV lane on the median), and all lanes (mainline and shoulders) will receive the rehabilitation treatment.

Project Team Composition

The project client is Caltrans District 4 (Oakland). The Project Engineer is Paul Mai (email: paul_mai@dot.ca.gov). The prime contractor has not yet been selected (the bid is in process).

Contract Type and Elements

This is a Design-Bid-Build contract with incentives and disincentives. The total amount of incentives and disincentives has yet to be announced. Major incentives will be associated with the total number of 33-h weekend closures, with an incentive bonus (yet to be identified) awarded for each weekend closure reduction up to the total incentive amount.

Work-Shift Schedules

Various, somewhat complicated, types of construction work-shift schedules will be adopted on the I-680 project, based upon a consideration of lane closure schemes, rehabilitation scope (renewal design), and construction locations, while attempting to minimize traffic disruption through the work-zone.

- Nighttime (8-h) Work (with partial lane closures)
  - Mill (cold-plane) existing AC pavement and place new AC pavement on HOV lanes and shoulders for about 45 lane miles.
  - Crack-seat (basically break) existing PCC pavement and place AC overlay pavement for about 60 lane miles.
- Daytime (8 to 10 h) work (with shifted traffic; no lane closures) to remove existing concrete pavement and place new base and new concrete [28-day curing-time Jointed Plain Concrete Pavement (JPCP)] pavement for about 20 lane miles.
- Extended weekend (33-h) work (with dynamic lane closures) for about 10 lane miles.
  - Remove existing concrete pavement and place new base and pre-cast concrete panel without post-tensioning
  - Remove existing concrete pavement and place new base and pre-cast concrete panel with post-tensioning

For Pre-cast rehabilitation work, two lane closure (work-shift) alternatives were compared for the transportation management plan (TMP) analysis: Alternative 1 [24 × 33-h weekend closures (Sat. 8:00 p.m. to Mon. 5:00 a.m.)]; and Alternative 2 [291 × 8-h weeknight closures (9:00 p.m. to 5:00 a.m.)]. Based on this comparison, the 24 repeated 33-h extended weekend closures schedule was determined to result in more productivity, which will reduce the overall project duration to half, compared to the conventional nighttime construction closure.

Specific Workforce Fatigue Factors

It is expected that about two thirds of the construction schedule (500 working days) will be conducted during nighttime work shifts, requiring the project team (Caltrans, CHP, and the contractors) to repeat about 8-h nighttime work shifts for about 350 days, which is about two construction seasons of continuous pavement renewal operations (mainly AC rehabilitation), working 5 nights per week. This long-term repeated nighttime work might result in cumulative fatigue among workers.

The I-680 project is designed to adopt so-called "dynamic lane configuration" for the 33-h weekend closures to most efficiently accommodate work-zone traffic. The project TMP requires the contractor to change the lane closure configuration eight times over the 33-h extended weekend closure, starting with four lanes open (4L) per direction through the work zone, then implementing lane openings of 3L, 2L, 1L, 2L, 3L, 2L, 1L, and 4L, using Quick-change Moveable Concrete Barriers. These dynamic lane configuration changes will require the contractor's crew to work under very tight work-zone space and schedule constraints.

In addition to the above-mentioned nighttime work, approximately 24 extended 33-h weekend work periods will be conducted over about 6 months. This non-stop construction will likely require a total of three to four back-to-back work shifts from Saturday night through Monday morning. This project could provide an excellent opportunity to compare the agency's and contractor's plans to deal with work force fatigue with their actual implementation, providing valuable lessons learned.

Attachment 1

Rapid Renewal Scenario Description Terms and Definitions

The project team followed these guidelines in compiling rapid renewal scenario examples, so that a standard set of terms would be used in describing different project examples.

Work Shift Schedules

The four basic highway construction work-shift schedules identified below refer to the basic highway construction schedule and highway construction worker schedules. Some workers may be required to follow more than one type of work-shift schedule during a single project or period of work.

- Extended day work, including 10-h shift, 12-h shift, and 12+ h shifts.
- Night work, including continuous night shift, temporary night shift, and rotating day/night shifts.
- Weekend work, including isolated weekend work, recurring weekend work, and combined weekday and weekend work.
- Continuous (24 × 7) work (nonstop construction) with two- or three-shift work, for periods of work for individual workers ranging between short–term (less than 1 week), midterm (1 to 4 weeks), and long–term (more than 1 month).

Additional Workforce Fatigue Factors

The following additional workforce fatigue factors represent work factors, in addition to work schedule, that have been shown to affect worker safety or performance in both the broader research literature and anecdotal accounts of rapid renewal highway construction.

- Location of Worksite Relative to Primary Contractor's Workforce, including work locations that are local to a primary contractor's workforce; work locations that result in an acceptable daily commuting distance from the primary contractor's workforce; and those that are distant, requiring extended commute times and/or on-site accommodations for the primary contractor's workforce. This factor is anticipated to affect worker fatigue by affecting the hours available for sleep.
- Job Category, including: State Manager, State Supervisor, and State Inspector; contractor On-site Manager and Supervisor; consultants; and highway workers.
- Typical Work Break Schedule, including meal timing and length and work break (other than meal time) timing and length.

Nature of Road Work

Following is a set of characteristics that can be used to describe the nature of rapid renewal highway construction road work being performed as part of a specific project.

- Concrete pavement renewal, including: jointed plain concrete pavement (JPCP); Pre-cast pavement renewal (post-tensioning or precast only); Continuous reinforcing concrete pavement (CRCP); normal Portland Cement Concrete (PCC) with 28-day curing-time mix; Rapid Strength Concrete (Rapid-set), including 4-h, 12-h, or 24-h curing-time mix; random-slab replacement; white-topping (PCC overlay); and full-depth concrete replacement (including new base).

- Asphalt concrete (AC) pavement renewal, including AC overlay, milling and filling (overlay) AC, and full-depth AC replacement (remove concrete and pave AC). Pavement materials may include normal AC hot mix asphalt (HMA) or rubberized AC.
- Pavement resurfacing, including AC pavement maintenance (sealing, crack-seal, cheap-seal, fog-seal, slurry-seal, or patches), pavement recycling (like cold-in-place AC recycling), diamond grinding of concrete pavement surface, and dowel-bar retrofitting.
- Non-pavement element renewal, including: shoulder renewal with mainline renewal; drainage; grading; fencing; guardrails and median barriers; retaining walls and sound walls; signage, lighting, traffic controls, and IS (information systems or intelligent systems); and utility relocation.
- Roadway widening, including widening for HOV lanes, high-occupancy toll (HOT) lanes, and general purpose lanes.
- Structure renewal, including bridge replacement or foundation replacement, approach slab replacement (for bridges or culverts), overpass-crossings, underpass-crossings, culverts and utilities, interchanges, ramps, and tunnels.
- Initial Highway Project, including new highway projects for extension or realignment.

Extent of Road Closure

Following is a classification of road closures. Individual categories may represent entire rapid renewal project examples or portions of larger projects:

- Maintaining all traffic lanes without closures through re-routing and traffic control measures.
- Shoulder closures.
- Edge lane or partial one-way closures.
- Full one-way, including single or multiple lane closures.
- Multiple lane two-way closures without full roadway closure.
- Full roadway closure.

Contract Type and Elements

Following is a classification of contract types and elements. Individual project examples may include multiple contract elements:

- Contract Types include Conventional (Design-Bid-Build), Design-Bid (turn-key), and A + B (Cost + Time).
- Contract Elements include incentives/disincentives, contract warranties (or pay-factor incentives), the requirement to use union or nonunion contractors, and environmental constraints.

APPENDIX B

Survey Instrument and Interview Guide

Survey Protocol for Fatigue Assessment

ID Code: ____________

First I'd like to ask some questions about you.

1) **What is your Job title?** ________________________

2) **Do you work for the government or are you a contractor?**
   - ☐ Government → ASK TO 2a
   - ☐ Contractor → ASK TO 2b

   a. **Do you work for DOT or an outsourced government agency?**
      - ☐ DOT → SKIP TO 2c
      - ☐ Outsourced → SKIP TO 2c

   b. **Are you a prime contractor or a sub or specialty contractor?**
      - ☐ Prime
      - ☐ Sub or Specialty

   c. **What kind of work are you doing at this job site? (SHOW CARD JOB LIST–CHECK ALL THAT APPLY)**
      - ☐ Project manager
      - ☐ Designer
      - ☐ Engineer
      - ☐ Field/Construction/ Traffic engineer
      - ☐ Inspector
      - ☐ Highway patrol service
      - ☐ Management
      - ☐ Superintendent
      - ☐ Foreman
      - ☐ Laborer
      - ☐ Operator
      - ☐ Truck Driver
      - ☐ Carpenter
      - ☐ Electrician
      - ☐ Traffic Controller
      - ☐ Other (specify)
      - ☐ ________________

   d. **Are you a Union member?**
      - ☐ Yes → Which union? (specify) ________________
      - ☐ No

   e. **Are you hourly or salaried (i.e., OT exempt employees)?**
      - ☐ Hourly
      - ☐ Salaried

3) **How many years of construction experience do you have? (READ RESPONSE OPTIONS)**
   - ☐ 5 years or less
   - ☐ 6 to 10 years
   - ☐ 11 to 15 years
   - ☐ 16 to 20 year
   - ☐ 21 to 25 years
   - ☐ More than 25 years

4) **How long have you worked at this job site? (READ RESPONSE OPTIONS)**
   - ☐ < 1 month
   - ☐ 1 to 6 months
   - ☐ 7 months to 1 year
   - ☐ more than 1 year

5) **Did you relocate for this job?**
   - ☐ Yes → ASK 5a
   - ☐ No → SKIP TO Q6

   a. **If Yes relocated: For how long?**
      - ☐ < 1 month
      - ☐ 1 to 6 months
      - ☐ 7 months to 1 year
      - ☐ more than 1 year

6) **(INTERVIEWER CODE. ASK ONLY IF NOT CLEAR) What is your sex?**
   - ☐ Male
   - ☐ Female

7) **How old are you?**
   - ☐ 18–24 years
   - ☐ 25–29 years
   - ☐ 30–34 years
   - ☐ 35–39 years
   - ☐ 40–44 years
   - ☐ 45–49 years
   - ☐ 50–54 years
   - ☐ 55–59 years
   - ☐ 60–64 years
   - ☐ 65 or older

8) What is your marital status?
- ☐ Single
- ☐ Cohabitating
- ☐ Married
- ☐ Divorced
- ☐ Widowed

9) Do you have any children under age 18 that live in your household at least part of the time?
- ☐ Yes → ASK 9a
- ☐ No → SKIP TO Q10

a. How many children under 18 live in your household at least part of the time?

1   2   3 or more

b. What is the age of your youngest child? ______

Schedule

Now I am going to ask some questions about your <u>current schedule at this job site.</u>

10) What is your usual schedule at this job site?
- ☐ Day
- ☐ Afternoon
- ☐ Night
- ☐ Other (specify)

a. What is your usual shift pattern (days × hours) for this job site?
- ☐ 5 × 8
- ☐ 4 × 10
- ☐ 4 × 12
- ☐ 5 × 12
- ☐ Other (days × hours)____________

b. What time do you usually start work? _____:_____ **a.m./p.m.**

11) What is the maximum number of hours you usually work per week? _________

12) Do you usually get at least 10 hours off between shifts?
- ☐ Yes
- ☐ No

13) Of the schedules/shifts you have worked, which one did you like the most?

a. SCHEDULE (Specify)__________   **b. SHIFT (D × H)**________

a. Why did you like this schedule/shift?

14) Of the schedules/shifts you have worked, which one did you like the least?

a. SCHEDULE (Specify)__________   **b. SHIFT (D × H)**________

a. Why didn't you like this shift/schedule?

Overtime and Time Off

15) How many hours did you work last week? _____ **hours**

a. How many of the hours you worked last week were considered overtime?
- ☐ 0 hours
- ☐ 1–5 hours
- ☐ 6–10 hours
- ☐ more than 10 hours

16) How many hours did you work two weeks ago (the week before last week)? __________ **hours**

b. How many of the hours you worked two weeks ago were considered overtime?
- ☐ 0 hours
- ☐ 1–5 hours
- ☐ 6–10 hours
- ☐ more than 10 hours

17) What was the longest string of consecutive days that you've worked at this job site? ______

18) Please look at show card B. When you have a day off, how often do you get at least 36 hours (a day and a half) between the time you leave work and the time you go back to work (SHOW CARD B)?
- ☐ Every Day Off
- ☐ Most Days Off
- ☐ Rarely
- ☐ Never

19) Compared with your schedule for the last 2 weeks, would you like to work more, less or about the same?
☐ More
☐ Less
☐ About the same

20) What's the shortest break you've had between two shifts at this job site? _____ hours

Seasonal/Other Work

21) Are you currently working another job to supplement your income?
☐ Yes → ASK 21a
☐ No

a. **If yes: How many hours per week do you usually work at the other job? _____**

22) How many months out of the year are you fully employed in highway construction? ____

a. **If less than 12: Do you usually work at another job when you aren't working in highway construction?**
☐ Yes
☐ No

23) How many more months do you think you will work on this job?___________ months

Breaks

Now I am going to ask you some questions about your breaks.

24) How many meal breaks do you usually get during the work day?____ meal breaks

IF 0 SKIP TO Q25

a. **How long do your meal breaks usually last (in minutes)? Meal breaks: _____ min**

25) How many other breaks do you usually get during the workday? ____ other breaks

IF 0 SKIP TO Q26

a. **How long do your other breaks usually last (in minutes)? Other breaks: _____ min**

Sleep Habits

Now I'd like to ask you some questions about your sleep habits.

26) I am going to ask you about situations when you might doze or fall asleep. Use the scale on show card C to choose the most appropriate number for each situation (SHOW CARD C AND READ RESPONSE OPTIONS BEFORE ASKING QUESTIONS):
0 = would *never* doze or sleep.
1 = *slight* chance of dozing or sleeping
2 = *moderate* chance of dozing or sleeping
3 = *high* chance of dozing or sleeping

Situation	Chance of Dozing or Sleeping			
a. Sitting and reading	0	1	2	3
b. Watching TV	0	1	2	3
c. Sitting inactive in a public place	0	1	2	3
d. Being a passenger in a motor vehicle for an hour or more	0	1	2	3
e. Lying down in the afternoon	0	1	2	3
f. Sitting and talking to someone	0	1	2	3
g. Sitting quietly after lunch (no alcohol)	0	1	2	3
h. Stopped for a few minutes in traffic while driving	0	1	2	3
Total score (add the scores up)				

27) Have you ever been told by a doctor or a nurse that you have a sleep disorder? Examples are sleep apnea, insomnia, and restless leg syndrome, but there are many other kinds.
☐ Yes → ASK 27a
☐ No

a. Have you ever received treatment for this sleep disorder?
☐ Yes
☐ No

Work/Sleep Calendar Last 48 Hours

For the next few questions, I am going to ask you to remember your work schedule and your sleep schedule for the past 48 hours (2 days).

IWER CODE ALL ON A 24-HR CLOCK—SEE CONVERSION CHART

Day before Yesterday	**Yesterday**	**Today**
43) The day before yesterday, what time did you get out of bed? ____:____ 24hr	37) Yesterday, what time did you get out of bed? ____:____ 24hr	31) Today, what time did you get out of bed? ____:____ 24hr
42) The day before yesterday, what time did you get to work? ____:____ 24hr	36) Yesterday, what time did you get to work? ____:____ 24hr	30) What time did you get to work today? ____:____ 24hr
41) The day before yesterday, what time did you leave work? ____:____ 24hr	35) Yesterday, what time did you leave work? ____:____ 24hr	**29) Current Time: ____:____ 24hr**
40) The day before yesterday, what time did you go to bed? ____:____ 24hr	34) Yesterday, what time did you go to bed? ____:____ 24hr	
39) Day off? (CIRCLE ONE) **YES or NO** If **YES** then <u>do not ask</u> Q41 or 42	**33) Day off? (CIRCLE ONE)** **YES or NO** If **YES** then <u>do not ask</u> Q35 or 36	
38) Day(s) of week (CIRCLE ALL THAT APPLY) **Sun Mon Tue Wed Thu Fri Sa**	**32) Day(s) of week (CIRCLE ALL THAT APPLY)** **Sun Mon Tue Wed Thu Fri Sa**	**28) Day(s) of week (CIRCLE ALL THAT APPLY)** **Sun Mon Tue Wed Thu Fri Sa**
Date(s)	**Date(s)**	**Date(s)**

Schedule and Sleep

44) What schedule/shift pattern allows you **the most** sleep per night?

___________(Schedule) __________(Shift)

a. How much sleep do you get per night with this schedule/shift pattern? _________(hours)

45) What schedule/shift pattern allows you **the least** amount of sleep per night?

___________(Schedule) __________(Shift)

a. How much sleep do you get per night with this schedule/shift pattern? ________(hours)

46) How many hours do you sleep per night . . .

a. . . . on your days off? ____________________________ (hours per night days off)

b. . . . while you are on vacation? ___________________ (hours per night vacation)

47) How many days per month do you get less than 4 hours of sleep within a 24-h period? ________ (days)

Experience of Fatigue at Work

For the next three questions, I am going to read you a few statements about fatigue. When I read the statement, please answer with one of the responses on show card D (SHOW CARD D).

48) Fatigue on the job is really not a problem—just something you can "muscle through."
- ☐ Strongly Disagree
- ☐ Disagree
- ☐ Agree
- ☐ Strongly Agree

49) Fatigue at work is a safety problem.
- ☐ Strongly Disagree
- ☐ Disagree
- ☐ Agree
- ☐ Strongly Agree

50) My level of fatigue at work is something I can control.
- ☐ Strongly Disagree
- ☐ Disagree
- ☐ Agree
- ☐ Strongly Agree

51) Have you ever unintentionally fallen asleep on the job during your usual work shift at this job site? (READ RESPONSE OPTIONS)
- ☐ Never → ASK 51c
- ☐ Once → ASK 51a & b
- ☐ More than once → ASK 51a & b

a. IF ONCE OR MORE THAN ONCE: Was this a day, afternoon, night, or other shift?
- ☐ Day
- ☐ Afternoon
- ☐ Night
- ☐ Other (specify)

b. How long was the shift? _________ hours

c. IF NEVER: Have you ever been so sleepy that you were afraid you might fall asleep on the job?
- ☐ Yes
- ☐ No

Please look at show card B.

52) Do you have difficulty staying awake during your commute home? (SHOW CARD B)
- ☐ Every Day
- ☐ Most Days
- ☐ Rarely
- ☐ Never

53) What is the usual length (in minutes) of your commute . . .
a. On your way to work? ________ min

b. On your way home from work? ___________ min

Symptoms and Effects of Fatigue on Job Performance

54) In one or two sentences, please describe what activities you usually perform at this job site.

55) Now I am going to read you a list of descriptions. Please rate, from 0 to 10, how well each one describes how you feel, at the end of your usual work day at this job site. Please refer to the scale on the show card where "0" means "not at all" and "10 means to a very high degree." (SHOW CARD–SCALE)

Description	Not at all										To a very high degree
a. Spent	0	1	2	3	4	5	6	7	8	9	10
b. Sleepy	0	1	2	3	4	5	6	7	8	9	10
c. Exhausted	0	1	2	3	4	5	6	7	8	9	10
d. Aching	0	1	2	3	4	5	6	7	8	9	10
e. Lack of initiative	0	1	2	3	4	5	6	7	8	9	10
f. Numbness	0	1	2	3	4	5	6	7	8	9	10
g. Drained	0	1	2	3	4	5	6	7	8	9	10
h. Tense muscles	0	1	2	3	4	5	6	7	8	9	10
i. Listless	0	1	2	3	4	5	6	7	8	9	10
j. Sweaty	0	1	2	3	4	5	6	7	8	9	10
k. Stiff joints	0	1	2	3	4	5	6	7	8	9	10

Description	Not at all										To a very high degree
l. Lazy	0	1	2	3	4	5	6	7	8	9	10
m. Uninterested	0	1	2	3	4	5	6	7	8	9	10
n. Overworked	0	1	2	3	4	5	6	7	8	9	10
o. Drowsy	0	1	2	3	4	5	6	7	8	9	10
p. Hurting	0	1	2	3	4	5	6	7	8	9	10
q. Indifferent	0	1	2	3	4	5	6	7	8	9	10
r. Passive	0	1	2	3	4	5	6	7	8	9	10
s. Falling asleep	0	1	2	3	4	5	6	7	8	9	10
t. Yawning	0	1	2	3	4	5	6	7	8	9	10
u. Worn Out	0	1	2	3	4	5	6	7	8	9	10

Work-Related Injuries and Accidents

Now I'd like to ask you about work-related injuries and accidents.

56) Have you ever had an injury while working on a road construction job?
- ☐ Yes → CONTINUE → What happened?

  ____

- ☐ No → SKIP TO Q59

If yes, ask the following:

a. Were you working the day, afternoon, or night shift?
- ☐ Day
- ☐ Afternoon
- ☐ Night
- ☐ Double
- ☐ Don't Remember

b. How long was the shift? ________ hours
- ☐ Don't Remember

c. Did the injury occur near the beginning, middle, or end of the shift?
- ☐ Beginning
- ☐ Middle
- ☐ End
- ☐ Don't Remember

57) Did you miss work because of the injury?
- ☐ Yes → ASK 57a
- ☐ No → SKIP TO Q58
- ☐ Don't Remember→ SKIP TO Q58

a. If yes—How many days did you miss? _______ days

58) Do you think that being tired was part of the reason for the injury?
- ☐ Yes → SKIP TO Q59
- ☐ No → ASK 58a

a. If NO—Was there something else that contributed to the injury?
- ☐ YES–Traffic
- ☐ YES–Distractions (e.g. cell phones, etc)
- ☐ YES–Other (specify) ______________________
- ☐ NO

Near Misses

59) Have you ever had a near-miss working on a road construction project? By that I mean a situation that might have resulted in a serious injury (if you hadn't acted in time)?
- ☐ Yes → CONTINUE → What happened?

____

- ☐ No → SKIP TO Q61

If yes, ask the following:

a. Were you working the day, afternoon, or night shift?
- ☐ Day
- ☐ Afternoon
- ☐ Night
- ☐ Double
- ☐ Don't Remember

b. How long was the shift? _____ hours
- ☐ Don't Remember

c. Did the near miss occur near the beginning, middle, or end of the shift?
- ☐ Beginning
- ☐ Middle
- ☐ End
- ☐ Don't Remember

60) Do you think that being tired was part of the reason for the near miss?
- ☐ Yes → SKIP TO Q61
- ☐ No → ASK 60a

a. If NO—Was there something else that contributed to the near miss?
- ☐ YES—Traffic
- ☐ YES—Distractions (e.g. cell phones, etc)
- ☐ YES—Other (specify) ______________________
- ☐ NO

Weather

Now I'd like to ask a few questions about the weather and how it affects you.

61) Do you feel more fatigued on the job when the weather is (READ RESPONSE OPTIONS—CHECK ALL THAT APPLY):
- ☐ Hot
- ☐ Humid (or muggy)
- ☐ Cold
- ☐ Rainy
- ☐ Overcast
- ☐ Windy
- ☐ Other → Specify
- ☐ None of the above

Please look at Show Card B.

62) How often does weather make you feel more fatigued on the job? (SHOW CARD B)
- ☐ Every Day
- ☐ Most Days
- ☐ Rarely
- ☐ Never

Fatigue Countermeasures

Now I'd like to ask you a few questions about things that might help prevent fatigue.

Training

63) Is fatigue a topic covered in your organizational safety training?
- ☐ Yes
- ☐ No
- ☐ Don't Know

64) Does your training include material on how to get a good night's sleep and reduce or avoid fatigue on the job?
- ☐ Yes
- ☐ No
- ☐ Don't Know

Napping

65) Do you ever take naps on your lunch break?
- ☐ Yes → ASK Q66
- ☐ No → SKIP TO Q67

If "Yes" TAKE NAPS, ask the following:

66) Where do you usually nap on your lunch break? (CHECK ALL THAT APPLY)
- ☐ In personal vehicle
- ☐ In worksite building/trailer

☐ Outside
☐ Off site
☐ Other, please specify: ____________________

Caffeine

I have just a few more questions for you.

67) Here is a list of some caffeinated beverages (SHOW CARD—LIST OF CAFFEINATED BEVERAGES); do you drink any beverages containing caffeine on days that you work?
☐ Yes
☐ No→ SKIP TO Q69

68) On days that you work, how many caffeinated beverages do you drink?
__________ caffeinated bevs.

Regarding the caffeinated beverages you drink on working days. . . .	YES	NO	DK
a. Do you bring your own to the work site?			▨
b. Are they available on site?			
c. Are they available nearby?			

Physical Exercise

69) Does your job have the flexibility to change tasks and move around to reduce fatigue?
☐ Yes
☐ No

70) When you feel fatigued on the job, do you get up and move around to restore alertness?
☐ Yes
☐ No

Those are all the questions I have for you, do you have any questions for me? ANSWER QUESTIONS IF THEY HAVE ANY. Thank you for taking the time to participate in our survey. GIVE RESPONDENT THANK YOU MONEY.

SME Interview Guide

Scheduling, Productivity

1. What kinds of crews do you have scheduled for this job (e.g., crew size, occupation/task groups)?

2. What kinds of shifts do you schedule on this job (e.g., days, afternoons/evening, nights, weekends; 5 × 8, 4 × 10, other)?

3. (How long are shifts) and what time do they start?

4. Which of these shift structures do you use most often or for the most employees?

5. Do workers usually have consistent shifts?

6. How far in advance do workers get their schedules?

7. Describe the process you use for scheduling work crews (e.g., how far in advance, who is involved in scheduling, what forms or software used).

8. What kinds of things do you consider when you make up a schedule? (site deliveries, time constraints, hours-of-service rules for crews)

9. On this project, are there penalties built in for not meeting certain deadlines? How does this affect crew schedules?

10. What kinds of complaints do you get from workers about their schedules?

11. What's the biggest challenge in scheduling work crews?

12. Please describe contract terms that would lead you to use "accelerated" scheduling (e.g., longer shifts than usual, nights, continuous weekends).

13. Please describe advance planning you do for any permitting required for lane closures or other work. How does this affect work scheduling?

14. How do extended schedules/overtime affect worker productivity? What do you do when you notice that workers are becoming less productive?

15. How does worker turnover affect productivity? Affect safety? Is scheduling an issue in worker turnover?

16. Do you engage in any team-building exercises with your work crews? (If yes): Please describe. How does team-building affect worker productivity? Worker safety?

Rapid Renewal Projects

17. A "rapid renewal project" is usually defined as one that minimizes the impact of construction on traffic flow, especially during peak periods, by conducting work during off-peak hours, using continuous weekend construction or extended nighttime operations and conducting work in zones adjacent to traffic. Does your project sound like a rapid renewal project? How is this project similar to a rapid renewal project? How is it different?

18. What term would you use to describe a rapid renewal project?

19. How would you describe a "traditional" road construction project (ask about bidding, contract elements, worker scheduling). How are rapid renewal projects that you have worked on different from traditional projects?

20. Would you say that most of the projects you have worked on are traditional or rapid renewal projects? Do you prefer one kind of project over the other? Why or why not?

Work Zone

21. Describe the physical layout of your work zone.

22. Describe the work zone safety practices that are usually used.

23. Are there any special work zone safety practices that are used during rapid turnaround projects? During night shifts? During extended shifts? Please describe.

24. Which, if any, of these work zone safety practices do you think have an effect on job performance (productivity)? Do you think they help with worker fatigue?

Training

25. Describe the kinds of things that are covered in safety training for workers on this job site.

26. Does training include information on how to get a good night's sleep? About how to reduce or avoid fatigue on the job?

Countermeasures

27. When do workers usually take breaks?

28. Do workers on this job site ever take naps on their breaks? Where do they go to nap?

29. Is there a place on the worksite (or nearby) where workers can get coffee or other caffeinated beverages? Are these beverages available at any time when people are working?

Workplace Injuries

30. What are some typical kinds of injuries that happen on road construction sites?

31. In your experience, are injuries more likely to occur on projects with extended or night-shift work? (Why or why not?)

32. Do you think fatigue can be a factor in these injuries (and how)?

33. What are the effects of workplace injuries? (on the crew, on the schedule, on costs)

34. Can you describe a specific example from this worksite or from another job?

Other, Possibly for DOT or Union Personnel

35. What are the typical contract elements that might affect how contractors schedule their work (and therefore, their crews)?

36. Please describe permitting requirements and procedures for contractors and subcontractors for lane closures or other work.

37. What state and federal agencies must be consulted for a project like this one? How do their rules affect work planning and worker scheduling?

38. What safety training and procedures does the state require? The federal government?

39. What, if any, are the state rules about worker schedules on road construction projects (shifts, hours-of-service, breaks)?

APPENDIX C

Fatigue Countermeasures

This appendix identifies and discusses promising techniques for fatigue management and mitigation in highway renewal projects. This material was reviewed in terms of the evidence supporting the impact on worker fatigue and performance and in terms of the potential applicability in the highway construction environments the team observed during field work.

Factors considered included demonstrated impact on sleep and performance, the extent to which laboratory studies can be generalized or implemented in field settings, the existence of field studies, enhancement of worker knowledge, and the overall preponderance of evidence and clinical experience. There have been relatively few "pure" field studies of fatigue countermeasures in the traditional experimental design model. Instead, much material is based on laboratory studies of controlled sleep duration, simulated performance tests, and field studies of fatigue reports or error in shiftwork populations. Thus, countermeasure recommendations are usually a result of synthesis of clinical experience, observation of trends, abstract experimental studies, and model-based sleep/wake regulation and circadian rhythm principles. The result is a list of fatigue countermeasures that are categorized according to a general "effectiveness" metric, which combines the team's assessment of the strength of evidence concerning impact on fatigue and performance, the duration of that impact, and the likelihood of application and adoption in the highway construction environment. This last aspect is essentially a judgment based on applied research and engineering knowledge and is meant to reflect the practical aspects of countermeasure application.

An additional classification for a number of countermeasures is "limited evidence or implementation complexities." This category was used for countermeasures that should work in principle but involve considerable technical complexity for implementation, have not been shown to impact fatigue or performance empirically, or entail medical supervision such as hypnotics and stimulants.

We adopted a classification scheme originally proposed by Co et al. (1994) for fatigue countermeasures in aviation operations. They distinguished *preventive* and *operational* countermeasures. Preventive countermeasures are used to "maximize general alertness" and tend to be used in off-work settings. Operational countermeasures are employed in the actual work setting to mitigate the effects of acute fatigue. While there are clear beneficial effects of many of the countermeasures to be discussed, Co et al. (1994) point out that there is no "magic bullet" for fatigue prevention and mitigation—it is important to take an eclectic approach, and to use measures that have been shown to work and that are adaptable to the circumstances at hand.

Table C.1. lists the countermeasures identified within the classification scheme described above. The subsequent pages of this section discuss each of these countermeasures from the standpoint of overall impact and potential implementation in the highway construction environment. This discussion is not meant to be a comprehensive review of evidence and individual research study parameters, but key references to selected studies are provided. Substantial portions of this section are based on material from McCallum et al. (2003), Dawson and McCulloch (2005), and Caldwell, Caldwell, and Schmidt (2008). This section is written in predominantly nontechnical language to facilitate the development of material appropriate for the operational environment.

1. Adequate Sleep

Preventing fatigue by ensuring adequate sleep opportunities, proper sleep-period timing, and appropriate accommodations.

Type of Countermeasure: Preventive

1.1 Basis

The most effective countermeasure for fatigue is to do as much as possible to prevent it from occurring in the first place. As the material in the literature review suggests, the

Table C.1. Fatigue Countermeasures Classified by Type and Judged Level of Effectiveness and Implementation Complexity

Impact	Countermeasure Type	
	Preventive	Operational
Generally Effective	• Adequate Sleep • Defensive Napping • Good Sleep Environment • Limiting Overtime and/or Work Schedule Modification	• Caffeine • Napping • Anchor Sleep • Rest Breaks
	• Fatigue Education	
Less Effective	• Diet	• Temperature and • Ventilation • Self- and Peer-Monitoring
	• Exercise	
Limited Evidence or Implementation Complexities	• Hypnotics or Stimulants • Model-Based Schedule Optimization • Fatigue Risk Management System	• Worker Status Monitoring and Alerting Technologies • Bright Light or Melatonin for Circadian Shifting

primary culprit for feeling fatigued is *sleep loss.* So, whatever can be done to obtain regular sleep and to prevent sleep loss should be high on the list of countermeasures. The principal advantage of getting enough sleep is that it will reduce on-the-job fatigue, thereby reducing the need for other countermeasures.

People tend to need, on average, 7.5 to 8 h of sleep in order to preclude feeling fatigued. While there are individual differences (Tucker et al. 2007), and some or complete sleep loss does not automatically lead to unsafe performance, it has been amply demonstrated that acute or chronic sleep loss leads to fatigue and safety risk (Van Dongen and Hursh 2010). Further, continued sleep loss results in cumulative effects (Van Dongen et al. 2003), and takes more than a single full sleep episode to recover from (Belenky et al. 2003). Hours-of-service rules tend to be based on the idea that restricting work time will provide sufficient opportunity for restorative sleep, but this idea does not hold up well to practical experience (Gander et al. 2011).

The first general strategy for minimizing sleep loss is to establish a routine approach to obtaining sleep that allows enough time to obtain sufficient sleep, takes time of day (circadian rhythm) into account, and ensures an appropriate sleep environment. Ideally, this would mean going to bed at the same time every night and waking up at the same time every day, allowing for at least 8 h of time in bed. This regularity, if properly linked to the individual's circadian rhythm (e.g., morning- and evening-types; Kerkhof and Van Dongen 1996) makes it easier to go to sleep, wake up, and recuperate fully each day.

Recognizing that regular sleep times are often not congruent with everyday life, it is important to point out that day-to-day variations in sleep timing and duration can be overcome by sleeping in on days off (Banks et al. 2010) and by supplementing sleep time with napping (Mollicone et al. 2008), provided that total sleep time is not curtailed in the long run. This is not recommended in individuals diagnosed with insomnia, where sleep regularity is one of the pillars of sleep hygiene and typically considered essential for treatment.

The sleep environment should be quiet, dark, and of comfortable temperature. Shift workers often change shift schedules from one week to the next or more frequently. This can lead to sleep loss because the brain is not adapted to sleeping at a different time of day. The best approach for reducing sleep loss associated with a new shift schedule is to start the new shift with no sleep debt. As a rule of thumb, this means getting at least 2 nights of unrestricted sleep before beginning a new schedule. If making a *radical* schedule shift, such as between days and nights, it will also be important to obtain some *compensatory* sleep prior to the new shift start (see discussion of defensive napping). For example, if the schedule starts at midnight Sunday, it would be desirable to get two full nights of sleep on Friday and Saturday, sleep as long as possible on Sunday morning, and try to nap for a couple hours before the start of the midnight shift on Sunday. Napping before extended periods of wakefulness will reduce fatigue and improve alertness.

A third general approach to minimizing sleep loss is to match sleep and work schedules to individual physiology. Morning people (i.e., "larks") perform best on work schedules with morning starts, but even for young people earlier than 7:00 a.m. is difficult. As an example, a study of construction workers on a typical three-shift system found that the day-shift workers got the least sleep, due to the 6:00 a.m. start time (Powell and Copping, 2010). Night people (i.e., "owls"), perform best on work schedules that start in the afternoon or evening. In either case, it is important that individual physiology be coupled with a sufficient main sleep period.

Countermeasures to Minimize Sleep Loss:

- Obtain sufficient sleep
- Have a regular routine for sleep
- Ensure the sleep environment is appropriate
- Start new shift schedules with minimal sleep debt
- Obtain *compensatory* sleep before new schedule
- Match regular work schedule to personal physiology: "lark" or "owl"

The limitations associated with this countermeasure tend to involve factors that often are beyond the control of the individual, such as work-shift start times, rotation of schedule, and location factors that might influence sleep, such as jet lag or the sleep environment. Additionally, some individuals tend to sacrifice adequate sleep for purposes of social or family activity; however, these factors involve individual choice and can be balanced as required.

1.2 Effectiveness

It is generally agreed in the fatigue research literature that adequate sleep is *the* most effective countermeasure to fatigue and performance decrements. The effects of adequate sleep last throughout the work period unless the work period is so long that it requires wake extension and thus causes sleep deprivation (although circadian rhythms will increase fatigue at night regardless).

1.3 Highway Construction Environment Implementation

Implementing the preventive countermeasure of adequate sleep involves a combination of worker knowledge and work schedule management to provide sufficient opportunity for sleep. As such, linkage to other countermeasures such as worker education and schedule management on the part of the construction contractor are important elements in getting adequate sleep.

2. Defensive Napping

Defensive napping as a fatigue countermeasure involves sleeping for a brief period prior to the work shift.

Type of Countermeasure: Preventive

2.1 Basis

Taking a nap can help to reduce fatigue and increase alertness on the job or at other times. Naps can be effective as a short-term countermeasure to fatigue or to compensate for periods when a worker will need to remain awake for a long time, such as when changing shifts.

Some general situations where napping would be appropriate are

- Less than 6 h for the main sleep period;
- Awake for 30 min or longer twice or more;
- Feeling as if continually drifting in and out of sleep; and
- Feeling much more tired than usual upon awakening from the regular sleep period.

Taking a nap should be timed to obtain the maximum benefit. This will vary depending on circumstances, but in general the following guidelines are applicable:

- Napping for longer periods (2+ h) before the start of a night shift can prevent fatigue for extended periods (e.g., through a night shift) and can be very beneficial (Dinges et al. 1987).
- Napping for short periods (less than 30 min) may result in subjective alertness (Tietzel and Lack 2001) but little is known about how long this effect provides actual benefits.
- Individuals who are day-oriented and not sleep-deprived avoid napping during the hours of 6:00 and 10:00 p.m., approximately, when alertness is usually high (the so-called wake maintenance zone).
- Schedule a nap during the mid-afternoon (1:00 to 3:00 p.m.) when alertness is low.
- Allow 15 to 30 min after a nap to become fully alert. The deeper the sleep the longer the period needed to become fully alert.

2.2 Effectiveness

Napping as a defensive measure reduces fatigue in the work period approximately in proportion to the duration of the nap (Mollicone et al. 2008). Further, the timing of the nap in relation to the work period is important, such that a nap closer to the work period is generally more effective.

2.3 Highway Construction Environment Implementation

As with the preventive measure of adequate sleep, defensive napping is a matter of individual worker knowledge and the opportunity to act on that knowledge *in advance of experiencing fatigue.* The latter aspect is related to work schedule management, notification of shift change, and providing sufficient advance notice to allow workers to use the time available to them to adjust through napping. In practice, the construction companies the team interviewed attempt to give at least a day off prior to switching from day to night shift.

3. Good Sleeping Environment

A good sleeping environment sets the stage for restorative sleep.

Type of Countermeasure: Preventive

3.1 Basis

Although most people can get used to almost any sleep environment, especially when they are exhausted, certain characteristics of where an individual sleeps can enhance or compromise how restorative a rest period is.

To ensure that sleep is restorative, sleeping environments must be quiet, dark, and comfortable.

To ensure a quiet environment, the individual should remove any noise sources, especially those that are unpredictable (e.g., pets in the bedroom). Use of earplugs to reduce traffic noise or other external sounds helps many people, as well as the use of a constant low-level noise source such as a fan.

The amount of light in a sleeping area can be reduced by using black-out shades, heavy dark fabric for curtains, or "hurricane shutters" over windows. Some people also use eyeshades in areas where there is substantial light leakage.

Comfort in the sleeping environment is related to the quality of the bed and the temperature. The bed and pillows should be of appropriate firmness for personal comfort and the temperature not too warm or too cold by personal preference.

Two additional environmental recommendations include orienting the clock face away so as not to worry about the time, especially when having difficulty falling asleep, and using the sleeping area only for sleeping—not other arousing activities such as work or watching TV and videos.

There may be practical limitations to controlling the physical elements of the sleep environment, especially when traveling. For example, some hotels do not provide room-darkening shades, or outside traffic noise may be unavoidable. However, an individual can prepare for some of these factors by carrying earplugs and eyeshades. It is also important to not invest too much psychologically in the need for certain sleep environment characteristics because this can lead to insomnia.

3.2 Effectiveness

The principal advantage to using this countermeasure is that an individual can adapt their sleep environment to meet individual needs and have a continuing positive effect on sleep quality.

3.3 Highway Construction Environment Implementation

The importance of sleep environment characteristics is primarily an educational issue. The fact that sleep hygiene principles are routinely suggested to individuals seeking sleep medicine consultation indicates the need for continuing education of workforces that may be subject to sleep disruptions. This can also include information to help modify family routines modification in order to facilitate sleep for the affected individual.

4. Limiting Overtime and/or Work Schedule Modification

Type of Countermeasure: Preventive

4.1 Basis

Evidence suggests that longer duration shifts and overtime are associated with increased incidence of error and safety-related incidents (Åkerstedt et al. 2002).

The reasons for this are complex, involving a combination of effects that lead to reduced performance with increasing time on task, neurobiological processes leading to increased homeostatic pressure for sleep, and possibly a generalized lowering of risk tolerance at particular points in the work cycle (otherwise known as "complacency").

The principal choices in limiting overtime or modifying the work schedule involve how long the shift will run, what time it will start, and which workers to assign. Hours-of-service (HOS) rules for transportation industries tend to limit the overall amount of work time, by specifying how long, for example, commercial drivers may spend behind the wheel. Alternative approaches to scheduling in the medical profession involve reducing the number of work hours for interns from over 80 per week to 60 per week. Similarly, HOS rules specify the maximum number of hours per day for certain professions (e.g., nuclear power plant operators); the minimal period between shifts, such as 10 h; and a minimum period off following a number of consecutive days of work. Later starting times appear to be associated with lower risk (Folkard and Åkerstedt 2004), and the prior schedule of the workers needs to be considered. For example, workers who have become adapted to afternoon shift work would be better able to adapt to night-shift start times than to rotate "backwards" to a morning start (Moog and Hildebrandt 1987).

Most of the research in this area is specific to a particular work environment, although risk modeling studies have identified common patterns across different working environments suggesting that shorter shifts are associated with lower risk. This must be balanced against the requirements of the work environment, and longer shifts (e.g., 12 h) may be acceptable if only a few are worked in succession (Åkerstedt 1998).

4.2 Effectiveness

Limiting work hours and work schedule modifications are associated with increased worker satisfaction and reduced incidence of errors on the job, by providing more time for sleep. These findings are sufficiently well-documented that they are the basis for various HOS rules mandated by the federal government and underlie various schedule analysis and modeling tools under development by the research community.

4.3 Highway Construction Environment Implementation

Implementation of this countermeasure in the rapid renewal highway construction environment involves a number of considerations. First, there appear to be only two basic shift ranges in the projects the team evaluated: day work (approximately 7:00 a.m. to 5:00 p.m.) and night work (approximately 7:00 p.m. to 5:00 a.m.). These schedules seem to be a blend of traditional work hours during the day and the need to accommodate late afternoon rush-hour traffic in the evening and be done by early morning. Thus, there are fairly rigid parameters associated with start and stop times that do not easily accommodate change.

Work scheduling during "regular" shifts, either day or night, appear to currently operate on the basis of project labor agreements (PLAs) for union states and common practice in non-union states. In either case, the usual approach to scheduling involves either 8- or 10-h shifts, with a maximum of a 55-h week. The usual minimum time off between consecutive work periods is 1.5 days.

Based on the team's observations of projects, the aspect of rapid renewal construction work that can most benefit from limitation of work hours or schedule modification is the practice of continuous weekend closures. These closures tend to run from 11:00 p.m. Friday evening to 5:00 a.m. Monday morning and are associated with considerable sleep disruption among managers and, possibly, laborers. Current practice on accelerated projects is to continue using the same workforce for another week of standard day or night work schedules following a weekend closure. The team's data suggest that workers show high levels of fatigue following this type of closure and resumption of a standard schedule. A simple modification to this practice is to provide workers Monday off following a weekend closure or at least to implement a later start time. The trade-off involves less work accomplished on that Monday, but this may still be a beneficial trade-off for the lower productivity expected of fatigued workers.

5. Fatigue Education

Type of Countermeasure: Preventive/Operational

5.1 Basis

An understanding of the fundamental nature of sleep loss, circadian rhythm, fatigue, performance impacts and amelioration strategies is a key element of both preventive and operational approaches to reducing fatigue. Education and training formed the basis of the highly successful NASA fatigue countermeasures program and over time led to a fundamental change in culture and philosophy regarding fatigue, both at the worker and management level. Education is a basic element of current approaches to fatigue risk management systems, and can help to overcome widely held misconceptions about the nature of the problem and ways to deal with it.

Key points to address in educational programs include the following (Caldwell et al., 2008):

- In the long run, there is no substitute for sleep.
- Fatigue is based on physiological mechanisms and cannot be overcome by motivation or willpower.
- Self-assessment is unreliable and potentially biased by work circumstances.
- Individuals vary in sleep need and responses to sleep loss, and responses are difficult to predict on a case-by-case basis.
- There is no "one-size-fits-all" solution.
- There are ways to prevent and mitigate fatigue, but they must be properly employed.
- Fatigue has safety, well-being, and economic consequences.

5.2 Effectiveness

Although training is sometimes considered a weak response to structural, organizational problems such as fatigue, it is a necessary first step in gaining commitment at the individual and corporate level to address the problem. Simply having an educational program is no guarantee of results, and some studies suggest that knowledge decays rapidly, while others indicate that higher levels of corporate commitment and engagement lead to longer lasting impressions.

5.3 Highway Construction Environment Implementation

While important as a fundamental component in fatigue management, translation of existing scientific knowledge into usable programs for employers and workers is not straightforward. The team's interviews with management SMEs suggested that fatigue is a topic of concern, and that there is some coverage of the topic in company safety training. However, the interviews yielded no material that would allow us to assess the quantity or quality of the training. The single source the team reviewed, "toolbox talks," yielded some relatively cursory material that was not contextualized to the rapid renewal environment.

Educational programs could be imported and adapted from transportation industries such as commercial aviation. Comprehensive and contextualized training about fatigue for the rapid renewal environment will need to address the specific risk factors and operational constraints of the work domain. These include long shifts, occasional double shifts, rapid switch to night work from day work, and continuous weekend closure effects upon sleep opportunity. At the present time there are no standards to guide contractors in their selection of consultants or material for fatigue training, nor is there a well-developed information dissemination pathway. This may be an appropriate role for industry association groups, which have established training material and guidance for other areas of safety concern.

6. Napping

Type of Countermeasure: Operational

6.1 Basis

Using napping as an operational fatigue countermeasure involves sleeping for brief periods during the work shift.

It is important to consider the following:

- Where to take the nap?
- When to take the nap?
- How long to nap?

These questions will have different answers depending on the nature of the work. The guidelines described for "defensive napping" are also applicable to napping during work periods, appropriately adapted.

In general the following guidelines specific to workplace napping are applicable:

- Taking 10- to 12-min "power naps" almost anytime as needed and appropriate can help refresh an individual for a short period of time.
- Being aware of the potential effects of sleep inertia following the nap and counteracting them with caffeine if necessary.
- Using napping as part of a continuous, nonsplit shift duty period and not using it to extend the duty period.

There may be times when workers feel overwhelmed by sleepiness despite "defensive naps" or a sufficient sleep period before work. In this case, they should take an "emergency nap" of 15 to 30 min as soon as the work activity permits.

6.2 Effectiveness

Naps of 20 to 30 min during appropriate periods of a work shift have been shown to improve performance and subjective alertness during the subsequent work period. Studies of extended shifts (16 h) have included naps of up to 2 h, although this has entailed more sleep inertia and potential interference with recovery sleep during the off-work period.

6.3 Highway Construction Environment Implementation

Implementing on-shift napping in a highway construction environment may be a considerable challenge. The team's field studies suggest that some workers do take naps during their lunch breaks or other times when it is appropriate, and they tend to use their personal vehicles as the location for napping. Due to the safety-critical nature of construction, workers must be very cautious about where and when they take breaks, particularly if they are asleep for a brief period. Personal vehicles as a location for napping are probably relatively safe, although ultimately it would be desirable to optimize the conditions under which naps are taken, in order to avoid excessive noise, vibration, overheated vehicles from sun exposure, and potential contact with construction equipment.

While there may be a larger percentage of nappers than are actually reporting on the survey, the issue is one that will ultimately require organizational commitment to be anything other than an informal, ad-hoc measure, which may result in disciplinary consequences. Management consensus from the team's field surveys was that napping during work was not acceptable, with a few exceptions.

7. Caffeine

Alertness can be increased by consuming caffeine in the form of coffee, tea, soft drinks, chocolate, caffeine gum, or nonprescription caffeine tablets (Table C.2.).

Type of Countermeasure: Operational

Table C.2. Caffeine Content from Various Sources

Percolated Coffee[a]	140 mg/7 oz
Brewed Coffee	80–135 mg/7 oz
Red Bull Energy Drink	115 mg/12 oz
Jolt Cola	72 mg/12 oz
Coca-Cola	34 mg/12 oz
Tea	70 mg/6 oz
Chocolate	5–35 mg/1 oz
No-Doz or Vivarin	200 mg/tablet
Excedrin	65 mg/tablet
Dristan	30 mg/tablet

[a] The caffeine content of coffee has been shown to vary considerably so this value should only be considered a general guide.

7.1 Basis

Caffeine is one of the most commonly used fatigue countermeasures, usually obtained through a cup of coffee. Other popular drinks and foods contain a lot of caffeine, including cola drinks, chocolate, and tea. Numerous medications also contain caffeine, as do "alertness aids" such as No-Doz and Vivarin. Caffeine is widely available, and taking a brief break to take caffeine can have the additional advantage of breaking up a tiring work routine.

Caffeine affects the nervous system within 15 to 20 min, depending on mode of ingestion. The effects include a more rapid heartbeat and increased alertness, and they last for about 4 to 5 h, but may last up to 10 h in especially sensitive individuals.

It is important to use caffeine only as a short-term way to boost alertness; regular use can lead to tolerance and various undesirable side effects, including insomnia and disrupted sleep if taken too close to bedtime.

Here are some situations where using caffeine makes sense:

- In the middle of a night shift (especially on the 1st and 2nd day of the work week when circadian disruption tends to be most pronounced and alertness most compromised).
- Mid-afternoon when the post-lunch alertness dip is greater because the individual did not get enough sleep.
- Prior to an early morning commute following a night shift, but not within 4 h of going to sleep if the individual is sensitive to sleep disruption from caffeine.
- Prior to a brief nap of 15 to 30 min, to reduce the effects of sleep inertia from the nap. Caffeine effects will become active as the nap is ending.

It is always best to try to reduce fatigue through obtaining enough sleep, but when this doesn't happen and boosting alertness for a period of several hours is needed, using caffeine makes sense.

Caffeine will affect sleep and should not be consumed 4 to 5 h prior to sleep, unless the individual is not sensitive to caffeine disruption of sleep. Caffeine in the body will make falling asleep more difficult, reduce sleep length, and disrupt the quality of sleep.

Our brains gradually build up a tolerance to repeated consumption of high levels of caffeine (e.g., five or more cups of coffee per day). A frequent coffee drinker needs a higher dose of caffeine to obtain the same "boost" effect of the more casual coffee drinker. Caffeine should be consumed sparingly, to "save the boost effect" for when it is really needed. That is, plan to use caffeine in the middle of the afternoon dip (1:30 to 3:30 p.m.) or, if working through the night, use it after midnight during the circadian low point.

7.2 Effectiveness

The alertness enhancing effects of caffeine have been well documented, and performance is increased on various measures when caffeine is used, particularly if people are sleep-deprived. There are, however, considerable individual differences in the effectiveness of caffeine. The duration of the effects is sufficient to counteract moderate levels of fatigue, when taken in time periods when fatigue will be a problem. Further, some putative sources of "energy," such as high sugar colas and energy drinks, are lower in caffeine per fluid volume than coffee, and tend not to have the same alerting effects as drinks with higher amounts of caffeine.

7.3 Highway Construction Environment Implementation

This countermeasure appears to be well-implemented on an individualized and informal basis in highway construction environments. Workers report either bringing their own caffeinated beverages to the job site or being able to obtain caffeinated beverages near the work site. Contractors may also consider providing coffee or other caffeinated beverages at a central location to the work site, for example, in the work site office, or at the location where gathering for "stretch and flex" safety meetings are held.

8. Anchor Sleep

Type of Countermeasure: Operational

8.1 Basis

Anchor sleep (or "split sleep") refers to a regular sleep period of at least 4 h, obtained at the same time each day. The anchor sleep period is supplemented by an additional sleep period taken when the schedule allows.

Some work schedules do not allow a full 8 h of sleep at the same time period every day. In order to effectively cope with schedules like these, workers should arrange to get at least 4 h of sleep at the same time every day; additional sleep can be obtained as the schedule permits.

Anchor sleep periods have the advantage of stabilizing the circadian rhythm to a 24-h period, so that workers will not constantly feel "out of sync." The anchor sleep period should be timed so that circadian rhythm high and low points correspond to work and sleep periods.

Anchor sleep is not a substitute for getting a full 8 h during any 24-h period. Instead, it is a coping mechanism meant to keep an individual's circadian rhythm synchronized to his or her daily schedule, by allowing sleep for a period of time when sleep is possible. It is important to supplement anchor sleep with supplemental naps that are sufficient to provide the complete sleep allotment needed on a daily basis. This countermeasure is helpful because it anchors the sleep cycle.

Research data indicate that it is important to have the anchor sleep period occur at a constant time every day. It is important to try to time the main or supplemental sleep episodes so that they do not coincide with circadian "forbidden zones" (wake maintenance zones) where initiation of sleep would be difficult—typically these times are approximately 8:00 a.m. to noon. (when not sleep deprived) and particularly 6:00 to 10:00 p.m.

Meals should be taken at the times that workers normally eat. When taking supplemental sleep, it is important that it not be too close to the anchor sleep period, or interference will occur. Caffeine consumption should be moderated during the use of anchor sleep as well, since the effects of caffeine last for about 5 h, and may interfere with either the anchor sleep period or the supplemental sleep in individuals sensitive to this effect.

Anchor sleep should be used as a coping mechanism for situations where a worker cannot get a full 8 h of sleep, but not as a routine. While split sleep periods may provide a sufficient amount on a short-term basis, getting a sleep allotment in a single episode is preferred.

8.2 Effectiveness

Laboratory studies of anchor sleep and split sleep periods indicate that performance tends to be maintained at levels equivalent to getting a consolidated sleep period. It is not known if performance stability is maintained over weeks to months on such schedules.

8.3 Highway Construction Environment Implementation

Use of anchor or split-sleep schedules would seem most appropriate for highway construction workers who are working on continuous closure operations, particularly management personnel who are not covered by a specific labor agreement for daily work hours. An example would be a manager who wishes to be present at the start of a closure on Friday evening, and work as much as possible through the following Monday morning. An anchor sleep strategy for this individual would be to nap in the mid-to-late afternoon on Friday in preparation for staying up all night starting late Friday night. The manager could then return home to sleep early Saturday morning and probably get about 4 h of sleep. The manager could return to the work site for several hours, then take another long supplemental sleep in the mid-to-late afternoon. This process would be repeated until the end of the closure on Monday morning.

9. Exercise

Type of Countermeasure: Preventive/Operational

9.1 Basis

Physical exercise has the principal benefit of improving overall cardiovascular health and muscle tone. Additionally, regular exercise improves sleep; individuals fall asleep quicker and sleep more soundly depending on the timing and the type of exercise. Exercise also enhances feelings of alertness for a short period.

Physical exercise can also be used to reduce the feeling of fatigue resulting from not getting enough sleep. Research indicates that brief periods of exercise can reduce feelings of sleepiness, although job performance does not improve. In rested individuals, a morning exercise break may improve alertness and driving performance for a brief period afterwards.

The health benefits of regular physical exercise are clearly established, and individuals should consider initiating a regular program of exercise or maintaining what they are already doing. If they work irregular hours or in situations that limit what they can do (e.g., no ready access to a gym; darkness), planning ahead and using alternative activities such as walking can maintain a healthy activity level.

Regular exercise will contribute to feelings of increased energy, by helping develop stamina and improving sleep. It should be a regular part of a healthy lifestyle.

While exercise will promote health and improve an individual's sleep, it does not permit them to cut back on primary sleep. Exercise can reduce immediate feelings of fatigue resulting from schedule changes and sleep deprivation, but that feeling only lasts for about 30 min. The effects of exercise on job performance are complex, and tend to wear off quickly, possibly even making performance worse in the afternoon. So, while an individual may feel better after exercising during a sleepy period on the job, they are still fatigued and should be aware that performance is likely to be compromised.

Do not exercise too close to bedtime, because increases in body temperature and alertness may make it difficult to go to sleep.

9.2 Effectiveness

Exercise as a fatigue countermeasure should be used primarily to develop cardiovascular health and to promote healthy sleep. As such, exercise is a complementary countermeasure and can facilitate the primary goal of getting adequate sleep. Exercise can be used as a very short-term countermeasure for brief enhancement of alertness, but the effects may not transfer to actual performance and will not last throughout the work period.

9.3 Highway Construction Environment Implementation

Implementation of this countermeasure in the highway construction environment as a preventive countermeasure may be promoted through the regular use of morning safety meetings and "stretch and flex" exercises that are part of this routine. It is common practice with some contractors to hold these crew-mustering meetings before starting work, to discuss recent safety concerns and to promote physical warm-up. These meetings could also be used as a platform for promoting regular exercise in the off-work hours to enhance health, restorative sleep, and general alertness. However, it should be borne in mind that well-intentioned advice to get up early to exercise is counterproductive for fatigue management if arising early curtails the sleep period.

10. Diet

This countermeasure involves varying meal content in order to increase alertness or promote sleep.

Type of Countermeasure: Preventive

10.1 Basis

The physical activity associated with eating can itself induce an alerting effect; however, current research evidence suggests that specific food content has little, if any, impact on level of alertness or feelings of sleepiness.

An attempt to extend an individual's endurance or promote sleep by altering the content of meals is unlikely to succeed. It is better to focus on consuming a nutritionally healthy and balanced diet at the appropriate times of day.

Getting a balanced, nutritious diet at appropriate times is often difficult for shift workers. Schedules often limit eating to what is available when time and work permit.

Individuals can avoid this situation with appropriate planning. Packing meals prior to leaving home, taking breaks where supermarkets are located, and take-out meals from (non-fast-food) restaurants are some steps that can be taken to make sure the right foods are available when needed.

Whenever possible, individuals should try to eat meals at times that correspond to their normal meal times; this will help maintain a regular sleep-wake cycle, since meals are a time cue that influences circadian rhythms. Conversely, the gastrointestinal system will process food best when it is eaten at the right times of day. One of the primary complaints of shift workers is gastrointestinal discomfort caused by being forced to eat at night when the body is not optimally prepared to handle the food intake.

Consuming large meals prior to sleep can disrupt the subsequent sleep period and also result in gastrointestinal discomfort.

10.2 Effectiveness

Eating properly is a key element of overall general health, which can contribute to quality and quantity of sleep. Eating or drinking specific foods or beverages (other than caffeine) for alertness enhancement is unlikely to work.

10.3 Highway Construction Environment Implementation

Good dietary habits and meal content could be part of an overall fatigue, health, and wellness training program for highway construction workers. There are no specific recommendations for dietary content for workers in this domain.

11. Rest Breaks

Rest breaks from the performance of a work task can reduce the effects of sleep loss for a short time.

Type of Countermeasure: Operational

11.1 Basis

Research studies have demonstrated that people who are sleep deprived or work on continuous but monotonous tasks during the night show degradations in their performance. However, if they take breaks, sometimes as short as 7 min, the degraded performance is reduced and they also report feeling better. The effects of rest breaks last only for 15 to 25 min, but this can be very important during critical tasks that are safety sensitive.

The break does not have to involve napping but simply a change in activity, such as stopping whatever task the worker is currently engaged in, walking around, stretching, talking to others, and so forth. The breaks may have more impact on fatigue later in the work cycle.

An additional benefit of rest breaks is that they temporarily remove workers from the work site and thus from potential risks.

11.2 Effectiveness

Rest breaks can provide temporary (15 to 25 min) relief from performance declines and subjective fatigue due to sleep loss. They are a short-term measure and not a substitute for adequate sleep.

11.3 Highway Construction Environment Implementation

Most highway construction jobs have some degree of self-paced structure, which would allow workers to take breaks when needed. There are certain multiperson, time-intensive tasks, such as pavement finishing, that would not be conducive to individual decisions to take a break, but with team support rest periods could be agreed upon.

Rest periods for "work to completion" kinds of tasks should be considered by construction superintendents and planned for on the basis of when fatigue is likely to be a problem, such as toward the middle or end of a night shift or closure period, or to break up a monotonous or physically demanding task.

12. Temperature and Ventilation

This countermeasure involves changing airflow and temperature in the surrounding environment to increase alertness.

Type of Countermeasure: Operational

12.1 Basis

Altering the airflow and temperature in the surrounding environment is fairly easy for most workers, through control of air conditioning or increasing fresh air by opening a window.

It is important to ensure that the air quality in the immediate operational environment is good, since fatigue is one of the symptoms often associated with impurities in the air. The fatigue that results from impurities can be a physiological reaction to reduced oxygen, and is an indication that the environment should be changed. For highway construction workers, air impurities might result from improperly ventilated exhaust systems or fumes from construction material such as asphalt.

Temperature tends to affect alertness indirectly, by changing the overall comfort level. If an individual is inclined to feel sleepy anyway, a warm environment may increase those feelings. However, the opposite is not true: there is little benefit to opening a window or lowering the temperature if an individual is already fatigued.

While there may be a brief effect of lowering the surrounding temperature or increasing airflow, research data suggest that the impact is very short and not likely to increase alertness for longer than a few moments. So, if an individual is feeling sleepy, it is best to use another countermeasure.

12.2 Effectiveness

Changing temperature or ventilation may enhance alertness, momentarily, but it is not an enduring effect and should not be considered a practical countermeasure.

12.3 Highway Construction Environment Implementation

Given the only momentary effects of changing temperature or ventilation, use of this countermeasure in the construction environment should be limited to supplementing short term other countermeasures, such as rest breaks or exercise.

13. Self- and Peer-Monitoring

Use of observational data to assess levels of fatigue in self or co-workers.

Type of Countermeasure: Operational

13.1 Basis

Performance impairment does not necessarily indicate fatigue, and self-report of fatigue does not necessarily indicate performance impairment, but the likelihood of either is increased in the presence of the other. For these reasons, it is important that workers pay attention to their own subjective state, as well as monitoring the quality of their work.

There are various rules of thumb that workers can use to self-monitor, including knowledge of their prior sleep-wake patterns; overt symptoms such as yawning, drooping eyelids, "catching" themselves falling into microsleeps; and feelings such as "fighting sleep"—items also featured in one of the most frequently used fatigue rating scales.

Research has shown that people are aware of their fatigue as it is developing and influencing their performance, including safety incidents, and that this awareness is strongly correlated with physiological measures of fatigue such as brain-wave measurements. The self-awareness of fatigue state needs to be linked to knowledge of proper actions (such as taking a break), so that people will not try to fight fatigue with relatively ineffective countermeasures. However, it is also known that fatigue impairs judgment and self-regulation, and so self-observation and report should not be relied upon exclusively.

Fatigue involves subjective feelings of tiredness, behavioral patterns of taking shortcuts and omissions, and a basis of physiology. Technological measures and most self-report rating scales of sleepiness or alertness tend to focus on the single dimension of momentary alertness. A more comprehensive representation of fatigue needs to address a broader range of underlying factors. This is important because not all jobs, workers, and tasks are the same, and they may be differentially vulnerable to different fatigue risk factors.

Observation of worker behavior by peers or supervisors relies on the observer's ability to distinguish specific behavioral characteristics indicative of impairment. There is very little applicable literature in this area concerning fatigue. A variety of symptom checklists have been employed by researchers, primarily as adjuncts to primary methods such as physiological or self-report measures. The checklists include facial markers such as eye closure, loss of facial muscle tone, and so forth as a basis for determining likely state of alertness. As with all such measures, these behaviors may occur without necessarily indicating an underlying state of fatigue, or the state of fatigue may be momentary. Vice versa, fatigue may be present without the overt symptoms, or with the overt symptoms occurring only occasionally and, therefore, being difficult to observe. The successful use of observational approaches depends on the ability of the observer to distinguish "normal" behaviors from those clearly indicative of impairment and to be able to do so on a near-continuous basis because fatigue is a dynamically changing state. This makes peer or supervisor observation an unreliable method for detecting fatigue. That said, workers should be encouraged to alert others when observing potentially fatigue-related behaviors, as the likelihood that fatigue is actually present is high when the symptoms are readily noticeable.

13.2 Effectiveness

Research indicates that individuals can reliably self-assess their own momentary state of fatigue, and less reliably assess others. The overall effectiveness of this approach depends on knowledge and ability to act on the assessment of fatigue. This becomes a matter of implementation.

13.3 Highway Construction Environment Implementation

The team's interviews with construction superintendents suggested that they have certain rules of thumb for determining when their crews are fatigued, including observation of erratic performance, facial characteristics, and irritability as well as knowledge of their prior schedule. Superintendents also state that they are aware of which individuals are more likely to be able to work certain hours and schedules, and of different individuals' propensity to fatigue. They construct schedules and assignments, to the extent they are able, on the basis of that knowledge.

These findings suggest that supervisory monitoring is already taking place, albeit on an informal basis. The team did not find any evidence that individual workers were encouraged to self-monitor and self-report, or that there were any formal or informal means to act on individual reports. All construction companies stressed that workers are encouraged to take hydration breaks whenever necessary.

The results indicate that there may be a role for approaches to "fatigue-proofing" highway construction environments through a combination of training on fatigue effects how to recognize them and more clearly establishing criteria for recognizing fatigue on the job and what to do about it. Examples from other work environments include using more humor and joking around on the night shift to see how people respond, and those showing unusually low response or irritability (compared to their usual personalities) would be watched or backed up more closely in safety critical tasks.

14. Hypnotics or Stimulants

Type of Countermeasure: Preventive

14.1 Basis

This countermeasure involves the use of synthetic or natural drugs to promote sleep when schedule changes interfere with falling asleep, or the use of synthetic or natural drugs to reduce the effects of sleep loss and enhance alertness under conditions of fatigue.

Hypnotics

If workers have a sudden change of schedule that interferes with their ability to go to sleep, there are drugs and herbal substances that can be used to promote sleep. Hypnotic drugs such as Ambien are part of a class of drugs that are useful for inducing sleep. These drugs reduce the amount of time required to fall asleep, improve ability to stay asleep, and can maintain sleep for 7 to 8 h.

Herbal remedies such as Valerian root, chamomile, kava, and lavender are promoted as sleep aids, but the evidence for their effectiveness is much less clear.

Sedatives and hypnotics have the advantage of being applicable to a number of situations that might interfere with sleep, such as shift changes, jet lag, or stress-related short-term insomnia. The drugs can help to alleviate these short-term problems and be discontinued to preclude the risk of dependency.

Depending on the specific type of drug class, there are changes in the nature of an individual's sleep although the significance of these changes is unknown.

It is possible to develop a dependence on hypnotics if used for a long period of time, and there is often a "rebound insomnia" in which sleep is slightly worse for one or two nights after discontinuing the drug even if used for only short periods of time.

If the drug is a particularly long-acting one, or if the individual has high sensitivity, there may be a "hangover" effect the next day where the individual may feel sluggish or show sleep inertia. Sleep inertia or actual inability to wake up while on hypnotics largely precludes their use during operations.

Hypnotics should be used only by prescription from a physician, and only for as long as necessary to "get over the hump" of sleeplessness, and this should be at the lowest clinically indicated dose for as short a time as possible. Hypnotics are an aid to achieve sleep schedule re-adjustment, not a preferred means for getting sleep over the long run.

Stimulants

Stimulants exert a physiological effect on the nervous system so that the effects of sleep loss can be temporarily reduced. Caffeine (discussed in a separate entry) is an example of a stimulant—one that does not require a prescription and that does not have any significant adverse side effects unless consumed in very large quantities.

Stimulants are particularly useful to the relatively small population of individuals who suffer from narcolepsy or other debilitating sleep disorders. Military personnel sometimes use stimulants during sustained operations, under controlled conditions, and supervised by a flight surgeon.

The effects of prescription stimulants such as dextroamphetamine and modafinil are clear-cut: Alertness is increased and performance is enhanced, relative to sleep-deprived individuals. These effects are also observed to some extent with a number of over-the-counter decongestants containing pseudoephedrine, and with herbal stimulants such as ephedra.

Synthetic stimulants such as amphetamine and modafinil are controlled substances and should only be used under the guidance of a physician for treatment of a specifically debilitating sleep disorder.

Herbal stimulants are unregulated, and the effects of many are unknown because of lack of proper evaluation. However, it is known that ephedra, in particular, is associated with heart attack and stroke, and it is likely to be controlled soon. All herbal stimulants should be considered as unproven and a safety hazard. Decongestants are not designed for increasing alertness—this happens as a side effect, along with increased drying of mucous membranes.

Even under the guidance of a physician, stimulants can have unwanted and potentially dangerous side effects, including changes in blood pressure and pulse, headaches, irritability, appetite loss, insomnia, nervousness, talkativeness, and sweating. Extreme reactions include hallucinations and paranoid psychosis.

Prescription stimulants are not generally permitted in operation of public transportation vehicles in the U.S. and many other industrialized nations. Randomized drug testing is regularly carried out to cut down on the usage of most known stimulants, at the threat of loss of job. These prohibitions may also apply to certain job categories in highway construction.

Most stimulants have a high potential for addiction and abuse because of the rapid euphoria that results from high doses. This can lead to a cycle of binging and crashing, and long-term abuse can lead to mental and behavioral disorders.

Finally, possession and use of controlled substances without a proper physician's prescription is illegal and can result in fines and jail time.

14.2 Effectiveness

Hypnotics and stimulants have demonstrated effects on sleep and alertness. Due to the controlled nature of these substances and the potential for legal problems and abuse, the team does not recommend systematic application in the highway construction environment.

14.3 Highway Construction Environment Implementation

Discussion of hypnotics and stimulants is usually a part of fatigue training in other domains, when discussed in conjunction with medical issues such as sleep disorder screening. Individuals should be encouraged to seek sleep disorder screening if they believe they have a problem or if management notices specific fatigue-related job performance issues.

15. Model-Based Schedule Optimization

This countermeasure involves using the knowledge of physiological processes controlling sleep and alertness to predict worker level of fatigue on the job.

Type of Countermeasure: Preventive

15.1 Basis

Research indicates that level of alertness at any particular point in time is controlled by three basic factors: (1) circadian rhythm, (2) prior sleep and wake history, and (3) length of time awake. Specific alertness values can be predicted from knowing where an individual is in their circadian phase, when and how long they slept during the last few days, and how long it has been since they woke up most recently. This conceptualization conforms to biology and common sense: An individual is naturally sleepy toward the late evening hours, sleeping recovers alertness, and alertness decreases the longer an individual is awake.

It is possible to use the general nature of these models to predict how an individual is likely to be feeling during a schedule change and through continued schedules such as night shifts and weekend closures. For example, if a worker is going to switch from day to night shifts, it is likely that he will wake up on the first day of the night shift at his usual time, such as 7:00 a.m. By the time he goes to work at 11:00 p.m., his alertness profile will be at the circadian high point, making it initially easier to stay awake, even though he would be habitually going to bed at this time. As he stays awake throughout the night, his alertness will decrease as it follows the circadian rhythm process. There will be no increased value on his sleep recovery process to balance that out, and the recovery sleep that is obtained will be curtailed because it is during the day.

Using knowledge of how alertness is affected by internal physiology can help individual workers and schedule planners to anticipate how fatigue crews will be at certain points in time, and to think about other potential countermeasures they might use, such as caffeine, a nap, or to the extent possible, schedule adjustments that will promote adaptation.

Alertness models are useful to estimate periods of reduced alertness so that specific countermeasures can be identified and used. Additionally, alertness profiles from the models can be used to design fatigue-friendly work schedules.

It is important to recognize that there are many other variables contributing to momentary alertness levels, such as stimulation level, other countermeasures employed, and individual differences in sleep need. Therefore, model predictions should be used as guidelines rather than as indicators of absolute predictions of alertness. This is not really a limitation; model predictions can effectively be used to compare different schedule options to see which is the most fatigue-friendly option and to identify the best times to deploy fatigue countermeasures.

Research with application of models in specific industrial settings has shown that there tends to be resistance to adopting model recommendations, which is predominantly due to a lack of training in how to interpret model predictions correctly. Models, like other tools, should be used with proper training on their inputs, interpretation of results, and appropriate uses. This training does not need to involve a major time commitment but without any training model predictions can be misunderstood, leading to bad scheduling or countermeasure decisions, and subsequent distrust of the modeling tool.

15.2 Effectiveness

Fatigue models are effective for providing estimates of risk of impairment under various schedules, can guide countermeasure application and timing, and can serve as an educational tool for understanding fatigue and its impacts. The limited evaluations of fatigue modeling in operational environments suggest that adoption and diffusion are limited at this time, and that organizational and work practice barriers may impede broad adoption.

15.3 Highway Construction Environment Implementation

Findings from the team's interviews with managers and superintendents in construction companies suggest that scheduling tools are used, but primarily by designers and engineers to develop task sequences for construction and for contractual compensation. Even the largest projects the team observed appear to be relatively "low-tech" when it comes to safety training and worker scheduling; they are performed more on the basis of standard practice and construction schedule needs than consideration of worker fatigue, although this does come into play over the long term. There is some prospect for combining fatigue modeling with analysis and scheduling tools that are used for highway projects, such as Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS). Construction projects that use software for worker scheduling could include fatigue prediction as an additional scheduling criterion at a relatively low investment cost, making model-based schedule optimization a promising technology for the near future. The team foresees that an industry association, such as Associated General Contractors (AGC), may champion such a modest investment as part of the development of Fatigue Risk Management Systems (FRMS), addressed in the next section.

16. Fatigue Risk Management System (FRMS)

A comprehensive program for addressing worker fatigue that is a component of an overall safety management system.

Type of Countermeasure: Preventive

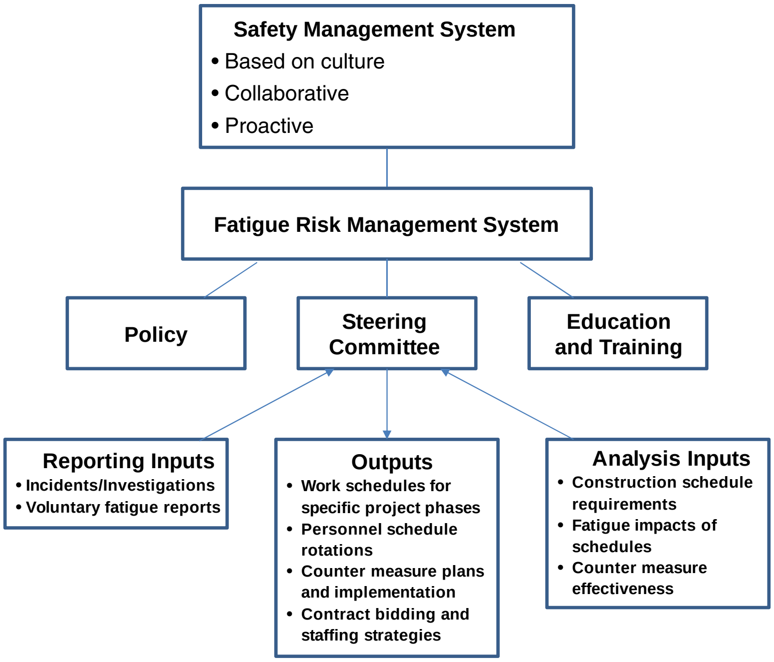
16.1 Basis

The concept of FRMS has evolved with the advances in fatigue science, modeling, and theories of organizational risk and error. Fundamentally, an FRMS is part of a "defense in depth" strategy for addressing a broad range of safety issues within an organization. FRMS are meant to be part of a safety culture and to provide a flexible means to address fatigue that is an alternative to prescriptive HOS rules.

The fundamental elements of an FRMS are shown in Figure C.1.

Key elements of such a program include incident reporting, including voluntary reports by workers and crew; monitoring of fatigue related information (such as reports and safety trends); modeling and assessment of work schedules; and tracking of related information such as absenteeism. Education and training programs are a fundamental part, as is a steering committee of actively involved staff to keep the system functioning.

FRMS have been implemented in a number of industries with round-the-clock operations, primarily transportation.



Adapted from Gander et al. 2011.

Figure C.1. Elements of a Fatigue Risk Management System (FRMS).

16.2 Effectiveness

The effectiveness of FRMS is unknown, in terms of overall impact of fatigue-related safety problems. Evaluation data concerning education is mixed, and there is one study suggesting a positive trend of increased sleep in personnel participating in an alertness management program. Other evaluation studies report increased awareness of fatigue, but also problems related to organizational change/acceptance. There are no set criteria or regulatory standards for developing or evaluating FRMS program content or for monitoring effectiveness of implementation. Transport Canada, however, has developed extensive toolkits for FRMS development in transportation, which can be easily adopted for other settings.

16.3 Highway Construction Environment Implementation

Given the range of contractors the team observed in this research—small and large, with projects ranging from moderate to very large—the team believes that full FRMS implementation in the highway construction environment would be premature. Safety programs and training seem to be the province of a single individual even in the very large programs, and the personnel or organizational infrastructure and the knowledge base for developing an FRMS, or for properly evaluating consultant offerings, does not appear to be available.

Instead of moving to full FRMS at this point in time, the team recommends that contractors and states adopt a more practical approach to fatigue management by drawing on the various tools that are already available, such as training, countermeasures, and alertness modeling. These tools could initially be tailored to individual contractor needs, although the team foresees the prospect of an industry association, such as AGC, offering standardized materials and approaches that address the range of highway construction environments.

17. Worker Status Monitoring and Alerting Technologies

Type of Countermeasure: Operational

17.1 Basis

Alertness monitoring involves tracking the performance or physiological measures of workers to determine if they are approaching drowsiness or impairment. *Operator status* monitors seek to measure and record, in real time, some physical or physiological features of the operator's eyes, face, head, heart, brain electrical activity, brain blood flow, muscular activity, reaction time, and so forth. *Embedded measure* technologies compare current operator state on some aspect of performance on the task at hand, such as lane deviation or steering variability in a vehicle.

Virtually all of these technologies are in the research stage. There is no research on how to best warn (alert) when a degraded state of impairment or drowsiness is detected. While some devices may be commercially available, there is not yet sufficient evidence about their reliability, validity, and effective use to warrant routine implementation.

Some of the questions that need to be answered include the following:

- What are "normal" versus safety critical "abnormal" values for the measures generated by the device?
- What constitutes acceptable performance for operators on a given task? Alternatively, are downward trends or gradual performance degradation seen?
- Could a perfectly safe operator be classified as "unacceptable" on occasions (e.g., score a false positive)?
- What measures are best for providing an "early warning" so that operators have not already gone too far into the impairment zone?

Suitable answers to these and other questions must be developed for each monitoring technology and for workers in each mode of operation.

17.2 Effectiveness

Although some reliability has been shown in laboratory situations, technological status monitoring for worker fatigue has not been effectively implemented in operational settings. Workers tend to find the technologies obtrusive.

17.3 Highway Construction Environment Implementation

This approach does not yet warrant consideration for implementation in the highway construction environment.

18. Bright Light or Melatonin for Circadian Shifting

Type of Countermeasure: Operational

18.1 Basis

The use of bright light as an operational fatigue countermeasure refers to timing the exposure to outside or bright indoor light in order to shift the circadian rhythm to correspond to a new work schedule or to acutely enhance alertness.

Melatonin is a hormone produced by the pineal gland in the brain, which is secreted during the evening and night hours. Synthetic or natural melatonin is used in high doses to induce sleepiness, adjust the circadian rhythm to new schedules, or both.

Bright Light

One reason that shift workers are sleep-deprived is that their circadian rhythms do not adjust from that of a day-oriented worker because of the constant exposure to day-oriented *time cues* such as bright light and social activity. Bright light can be used in several ways to help overcome fatigue:

- Bright light exposure in the evening shifts the circadian rhythm to a later time, such that maximum drive for alertness shifts from the evening to the night.
- Bright light exposure in the early morning shifts the circadian rhythm to an earlier time, such that maximum drive for alertness shifts from the evening to the afternoon.
- Day-to-day bright light exposure carefully adapted to the shifting circadian rhythm can result in further shifts to later or earlier times as desired.
- Bright light exposure at any time of day also results in an acute alertness boost, which lasts as long as the light exposure continues.

It should be evident that achieving the desired effect from bright light—to adapt to a new work schedule, for example—requires careful planning of the time of administration, knowledge of the present state of the circadian rhythm to figure this out, and avoiding bright light at times when it is not supposed to be administered. In practice, therefore, only the acute alerting effect of bright light can be effectively achieved. There may, however, be side-effects of unintended circadian shifts, which may make it difficult to readjust to a normal schedule, for instance after a weekend closure with much nighttime bright light exposure.

Using light exposure for several hours over a period of several days is usually most effective in shifting the circadian rhythm, although periods as short as 30 min have been shown to have an effect. The light exposure that will be most effective is in the range of 3,000 to 10,000 lux—much beyond that obtained simply from indoor lights—and blue light is especially effective. Indoor light, however, also has the capacity to shift circadian rhythms if no bright light exposure is experienced, and the light sources typically used during road construction projects probably also have this capacity. Use of lighting to shift circadian rhythms or increase alertness may not be feasible in some work environments where night vision is required or where there is a need to maintain low light levels (e.g., cabs of equipment such as backhoes or loaders).

Use of light exposure for resetting the circadian rhythm is a complex undertaking and should be guided by a person knowledgeable in circadian physiology. Additionally, the benefits of resetting the circadian rhythm can be maintained only through fairly rigid adherence to the procedure, and ensuring that other time cues (e.g., daylight) are minimized. That is, in addition to *light* exposure, it is also important to control the timing of *darkness.* This is especially true for those workers who may be traveling between work and home in the bright morning sun. In these cases, it is important to minimize exposure to the sunlight by wearing dark glasses (special goggles are recommended).

Melatonin

Melatonin in pharmaceutical doses (0.3 to 5 mg) has fairly rapid sleep-inducing effects, and lowers alertness and body temperature following administration. When combined with proper timing and managed light exposure, melatonin can help to adjust the circadian rhythm to a new schedule by shifting the circadian rhythm.

Like bright light, melatonin can be used in several ways to help overcome fatigue:

- Melatonin administration in the evening shifts the circadian rhythm to an earlier time, such that maximum drive for sleep shifts from the night to the evening.
- Melatonin administration in the morning shifts the circadian rhythm to a later time, such that maximum drive for sleep shifts from the night to the morning.
- Day-to-day melatonin administration carefully adapted to the shifting circadian rhythm can result in further shifts to earlier or later times as desired.
- Melatonin administration at a time of day when sleeping is normally difficult opens the gate for sleep.

Note that the circadian rhythm-shifting effects of melatonin work in the opposite direction as those of bright light.

The timing of melatonin is an important factor; it needs to be taken in the proper relationship to the body's biological rhythm in order to achieve the desired effect. Using melatonin to *delay* the circadian rhythm is especially complicated because of the interaction with daylight, which is a more powerful adaptation mechanism. As with bright light, use of melatonin for resetting the circadian rhythm is a complex undertaking, and it should be guided by a person knowledgeable in circadian physiology. Additionally, the benefits of resetting the circadian rhythm can be maintained only through fairly rigid adherence to the procedure and ensuring that other time cues (e.g., daylight) are controlled.

The Food and Drug Administration does not regulate the sale of melatonin, so the quality of products available in health food stores and other outlets is uncertain.

Because use of melatonin can cause drowsiness, it should not be taken if an individual intends to drive or engage in other complex or potentially dangerous activity.

The sleep inducing effects of melatonin are temporary, so while individuals may be able to get to sleep at an unusual time by using melatonin, they may not be able to stay asleep for as long as desired. Additionally, various side effects of melatonin have been reported, including worsened fatigue, depression, coronary artery constriction (possibly increasing heart attack risk), and possible effects on fertility. For these reasons, it is important to use melatonin only under the guidance of a properly trained physician.

18.2 Effectiveness

Both bright light and melatonin have been shown, under proper circumstances, to facilitate re-adjustment of the circadian rhythm. Light also has an acute alerting effect which is, however, transient. These countermeasures are difficult to deploy effectively and reliably in an operational environment; thus, they are not considered effective for the highway construction environment.

18.3 Highway Construction Environment Implementation

Bright light and melatonin are not recommended for use by highway construction contractors or state agencies. Individuals may seek medical advice regarding their application, but they should not be generally promoted by the organization.

APPENDIX D

Fatigue Risk Management Schedule Guidance and Work Practices

This appendix contains work schedule guidance and work practice recommendations for the range of shift schedules commonly encountered in rapid renewal construction. The guidance consists of fatigue models for each basic work-schedule type (Day Shift, Night Shift, Weekend Closure, Switching Shifts, Manager and Designer), typical schedule variations for a few basic types, and both preventive and operational fatigue countermeasures tailored for each work schedule type. Included are work start and stop times, likely sleep times, and assumptions made in preparing schedule-based fatigue models. Issues of concern for each schedule type are discussed, including the overall profile of fatigue during the work period; cumulative impacts; and potential countermeasures to apply, including modifications to shift length, days off prior to switching shifts, rest breaks, and so forth.

The Fatigue Management Key Points starting on this page provide a brief introduction to the major principles in fatigue management, which are derived from schedule-based fatigue modeling. To determine likely fatigue levels of personnel on a daily and weekly basis, turn to the pages containing the shift type(s) of interest. For the Day and Night schedules, a number of variations are included as well. Subsequent pages contain details specific to schedule variations within that basic schedule type. Weekend closure, shift switching, and manager examples use a 50-h week as the "base" schedule, but fatigue profiles, assumptions, and countermeasures also apply to longer and shorter work weeks within that schedule type.

These shift profiles and countermeasures are intended as guidance only; they are meant to provide managers with information to make decisions about specific work assignments and for planning overall construction schedules to balance worker fatigue management with project schedule goals. There is no one-size-fits-all solution for a project or for an individual worker. This guidance is intended to assist managers in achieving a balance between project objectives and worker fatigue management.

Fatigue Management Key Points

- Day shifts have substantially lower fatigue levels than night shifts, including peak fatigue (Figure D.1.).
- Fatigue accumulates over time if it is not relieved through sufficient sleep. Fatigue is highly likely to accumulate while working night shift (Figure D.1.).
- Brief naps at appropriate times in the work period, especially on a night shift, reduce immediate fatigue and its accumulation over time (Figure D.1.).
- Restricted sleep (sleep lost due to work demands, family demands, social activities, stress, etc.) can affect fatigue for several days and may take more than a single night of good sleep to recover from (Figure D.2.).
- The time night shift ends largely determines fatigue levels; earlier shift end times reduce peak fatigue during the shift and also slow accumulation of fatigue over time. (Figure D.3.).
- Day shifts, if they are very long, can also result in increased peak fatigue and accumulation of fatigue over time—for example, a designer or manager working a high-production schedule of 80 h per week (Figure D.4.).

Day Shift Schedules

Example: 40-h Week

(5 days × 8 h per day)

Application

Standard, non-accelerated construction.

Shift Start Time:	7:00 a.m.
Shift End Time:	3:30 p.m.
Bedtime:	10:00 p.m.
Wake Up:	5:30 a.m.

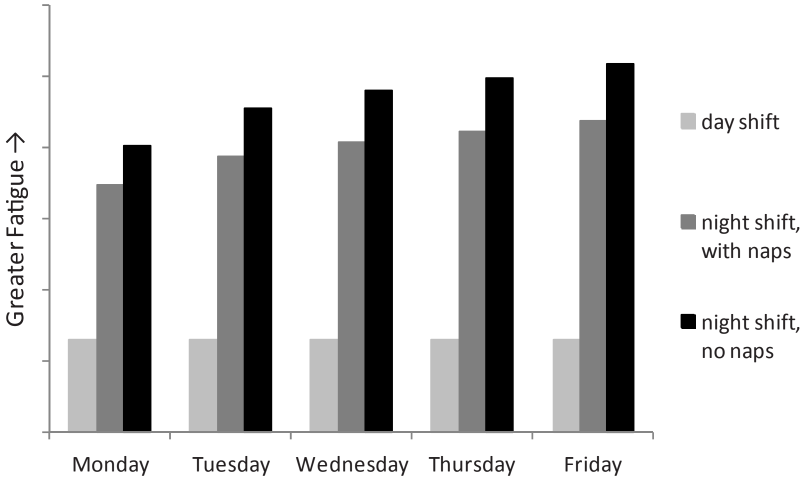


Figure D.1. Peak fatigue: 5 × 10 (50-h week) day shift and night shift with and without naps.

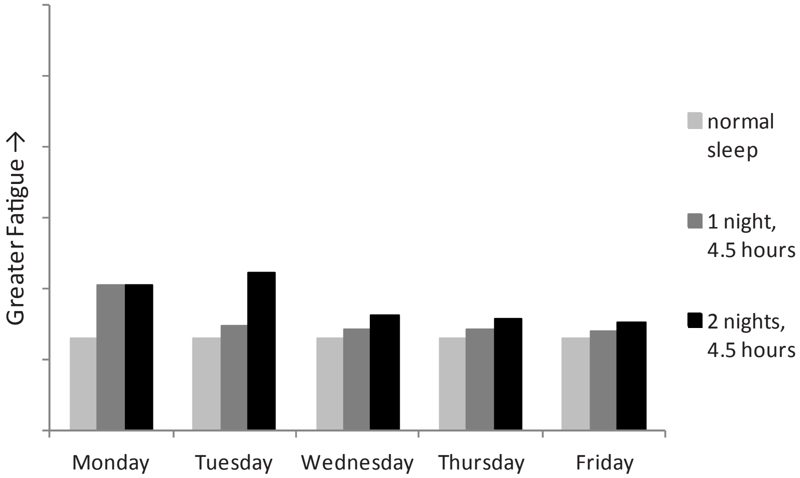


Figure D.2. Peak fatigue: day shift with normal sleep (7.5 h per night) and 1 and 2 nights' restricted sleep (4.5 h).

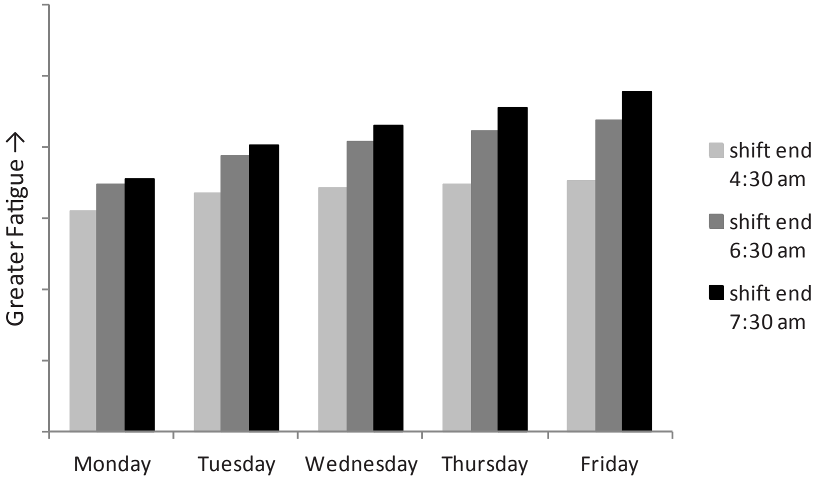


Figure D.3. Peak fatigue: night shift with various work stop times.

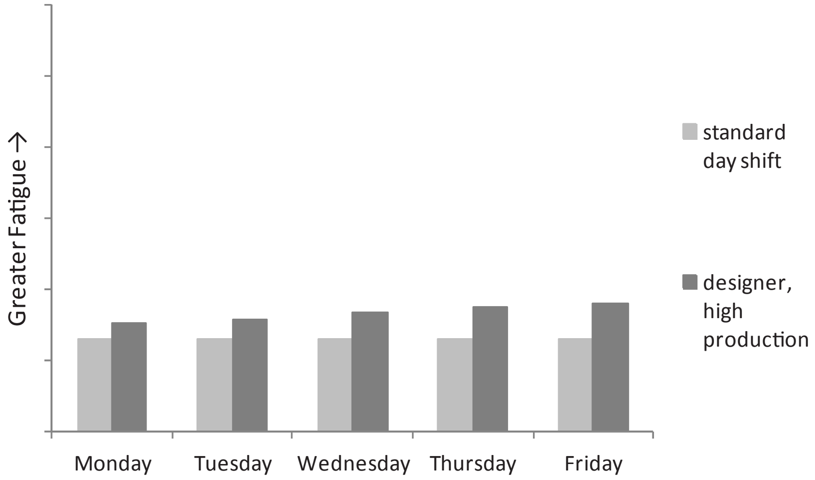


Figure D.4. Peak fatigue: high production designer or engineer schedule versus typical day schedule.

Assumptions

- 30-min meal break
- 1-h commute
- 7.5 h of sleep nightly
- 30 min of personal time between waking up and starting work

Fatigue Profile

Fatigue peaks just after noon, declines toward evening, and then rises sharply before bedtime. (Figure D.5.).

Preventive Countermeasures

- Maintain consistent sleep and wake times throughout the week.
- Maintain similar or identical sleep and wake times on weekend or nonwork days.

Operational Countermeasures

- Caffeine during day, but no later than 4:00 p.m.
- Strategic naps (on-the-job) to reduce impact of restricted sleep.
- Consume caffeine just before strategic naps to counteract sleep inertia on waking.
- Self-selected rest breaks to reduce fatiguing impacts of monotonous tasks or highly complex tasks.

Comments

- With each of the following conditions there is the potential for fatigue to accumulate over time as sleep duration declines:
  - ○ *Shifts that are longer than 10 h* (see variations) may lead to reduced sleep durations due to a later arrival time home and the need for additional time for personal activities.

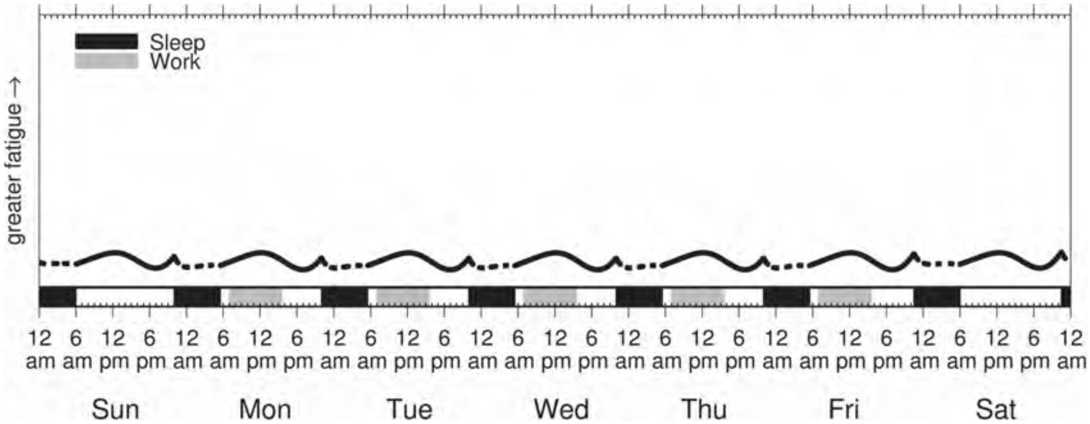


Figure D.5. Fatigue profile: day shift schedules.

- *Shifts that begin before 7:00 a.m.* may lead to reduced sleep durations because individuals may not be able to compensate for an earlier wake time by going to bed earlier.
- *Commute times longer than 1 h each way* may lead to reduced sleep durations due to both an earlier wake time and a later arrival time home.

Day Shift Schedule Variations

The same assumptions, fatigue profile, recommended countermeasures, and general comments apply for all day shift variations.

48-h Week

(4 days × 10 h per day, 1 day × 8 h per day)

Application

Accelerated schedules, day shift, with or without use of two-shift construction with nighttime closures and break during evening rush hour.

	Mon. to Thur.	Fri.
Shift Start Time:	7:00 a.m.	7:00 a.m.
Shift End Time:	5:30 p.m.	3:30 p.m.
Bedtime:	10:00 p.m.	10:00 p.m.
Wake Up:	5:30 a.m.	5:30 a.m.

50-h Week

(5 days × 10 h per day)

Application

Accelerated schedules, day shift, with or without use of two-shift construction with nighttime closures and break during evening rush hour.

Shift Start Time:	7:00 a.m.
Shift End Time:	5:30 p.m.
Bedtime:	10:00 p.m.
Wake Up:	5:30 a.m.

60-h Week

(5 days × 12 h per day)

Application

Accelerated schedules, day shift, with or without use of two-shift construction with nighttime closures and no break for traffic.

Shift Start Time:	7:00 a.m.
Shift End Time:	7:30 p.m.
Bedtime:	10:00 p.m.
Wake Up:	5:30 a.m.

Night Shift Schedules

Example: 40-h Week, Monday Night Start

(5 days × 8 h per day)

Application

Second shift for continuous construction with break for evening rush hour traffic. May be used with 5-h closures (e.g., 10:00 p.m. to 3:00 a.m.) in urban areas that require longer periods for morning and evening rush hours (e.g., New York, Los Angeles).

Shift Start Time:	8:00 p.m.
Shift End Time:	4:30 a.m.
Bedtime, After Shift:	6:30 a.m.
Wake Up, After Shift:	1:00 p.m.
Total Sleep, After Shift:	6.5 h

Assumptions

- 30-min meal break
- 1-h commute
- 1 h of "down time" between arriving home after work and going to bed
- 1:00 p.m. wake time

Fatigue Profile

Fatigue level rises steeply throughout the shift and commute home to a maximum just before going to bed. Peak fatigue increases each shift until early Saturday morning. Very high fatigue levels during shifts are primarily the result of being awake during a phase in the circadian cycle when there is substantial pressure to sleep. The progressive increase in overall fatigue throughout the week (*cumulative* fatigue) is the result of sleep loss while working night shift. Sleep durations are significantly shorter than for day shifts because of circadian

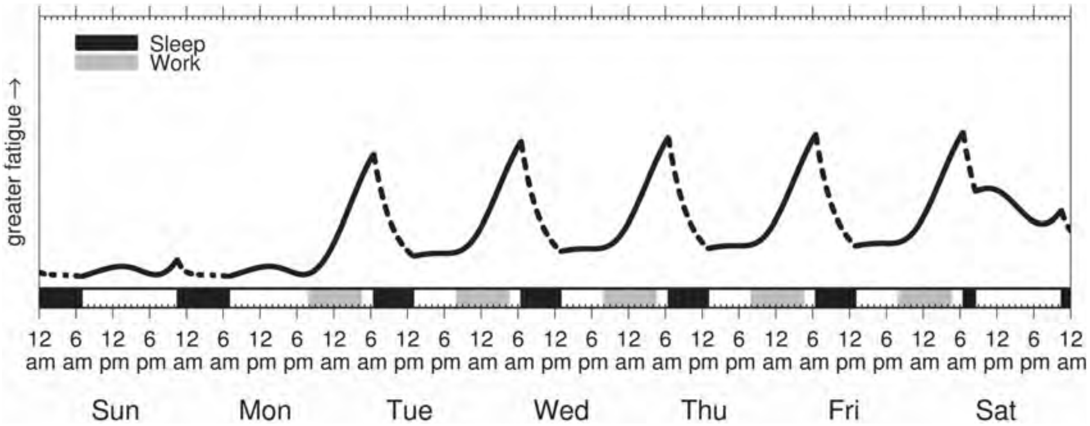


Figure D.6. Fatigue profile: night shift schedule ending at 4:30 a.m.

rhythm influences: for shifts ending at 4:30 a.m., a maximum sleep duration of 6.5 h due to circadian pressure to wake around 1:00 p.m. (Figure D.6.).

Preventive Countermeasures

- Defensive nap in the afternoon before beginning night shift.
- Return to day schedule (sleeping at least 8 h per night) on days off, following a morning nap on 1st day off from nights.
- Sleep in on the weekend to make up for sleep loss during the week.

Operational Countermeasures

- Caffeine during the shift, but no later than 5 h before bedtime.
- Strategic naps (on the job) to reduce impact of shortened sleep periods. A mid-shift nap substantially reduces peak fatigue within and across shifts and reduces cumulative fatigue.
- Consume caffeine just before strategic naps to counteract sleep inertia on waking.
- Self-selected rest breaks to reduce fatiguing impacts of monotonous tasks or highly complex tasks.
- Supervisory monitoring for signs of fatigue and application of countermeasures.

Comments

- With each of the following conditions there is the potential for fatigue to accumulate over time as sleep duration declines:
    - *Shifts that end later than 4:00 a.m.* (see variations) will lead to reduced sleep durations due to circadian pressure to wake around 1:00 p.m. Longer night shifts tend to end later, resulting in later bedtimes; long night shifts should be used sparingly.
    - *Commute times longer than 1 h each way* may lead to reduced sleep durations due to a later bed time.
- *Returning to a day schedule on days off* may not substantially increase sleep duration compared with staying on a night schedule, but it is likely to result in improved sleep quality and less disruption to daily activities.

Night Shift Schedule Variations

The same assumptions, recommended countermeasures, and general comments apply for all night shift variations.

48-h Week, Monday Night Start

(4 nights × 10 h per night, 1 night × 8 h)

Application

Second shift for continuous construction with break for evening rush hour traffic. Potential for use with 8-h closures (e.g., 9:00 p.m. to 5:00 a.m.) in urban areas.

Shift Start Day:	Mon. to Thur.	Friday
Shift Start Time:	7:30 p.m.	7:30 p.m.
Shift End Time:	6:00 a.m.	4:00 a.m.
Bedtime, After Shift:	8:00 a.m.	6:00 a.m.
Wake Up, After Shift:	1:00 p.m.	1:00 p.m.
Total Sleep, After Shift:	5 h	7 h

50-h Week, Monday Night Start

(5 nights × 10 h per night)

Application

Second shift for continuous construction with break for evening rush hour traffic. May be used with 7-h closures (e.g., 10:00 p.m. to 5:00 a.m.) in urban areas.

Shift Start Time:	8:00 p.m.
Shift End Time:	6:30 a.m.
Bedtime, After Shift:	8:30 a.m.
Wake Up, After Shift:	1:00 p.m.
Total Sleep, After Shift:	4.5 h

55-h Week, Monday Night Start

(5 nights × 11 h per night)

Application

Second shift for continuous construction with break for evening rush hour traffic. May be used with 8-h closures (e.g., 9:00 p.m. to 5:00 a.m.) in urban areas.

Shift Start Time:	7:00 p.m.
Shift End Time:	6:30 a.m.
Bedtime, After Shift:	8:30 a.m.
Wake Up, After Shift:	1:00 p.m.
Total Sleep, After Shift:	4.5 h

60-h Week, Monday Night Start

(5 nights × 12 h per night)

Application

Second shift for continuous construction with break for evening rush hour traffic. May be used with 11-h closures (8:00 p.m. to 7:00 a.m.) in rural areas where there is little or no rush hour traffic.

Shift Start Time:	7:00 p.m.
Shift End Time:	7:30 a.m.
Bedtime, After Shift:	9:30 a.m.
Wake Up, After Shift:	1:00 p.m.
Total Sleep, After Shift:	3.5 h

Comment on Night Shift Variations

- *Peak fatigue levels and cumulative fatigue effects* become more pronounced as shift end times get later, but the same general pattern holds for all night-shift variations.

55-H Weekend Closure, Day Shift

Day Shift, 50-h Week Base Schedule

(5 days × 10 h per day on weekdays, 2 days × 12 h per day on weekend, for 12 consecutive days worked)

Application

Accelerated schedules, daytime portion of two-shift continuous construction with break for evening rush hour traffic during the week, switching to 12-h shifts for closure period. Used with 55-h (10:00 p.m. Friday to 5:00 a.m. Monday) weekend closure.

	Mon.–Fri. Week 1	Sat.–Sun. (closure)	Mon.–Fri. Week 2
Shift Start Time:	7:00 a.m.	7:00 a.m.	7:00 a.m.
Shift End Time:	5:30 p.m.	7:30 p.m.	5:30 p.m.
Bedtime:	10:00 p.m.	10:00 p.m.	10:00 p.m.
Wake Up:	5:30 a.m.	5:30 a.m.	5:30 a.m.

Assumptions

- 30-min meal break
- 1-h commute
- 7.5 h of sleep nightly
- 30 min of personal time between waking up and starting work

Fatigue Profile

Fatigue peaks just after noon, declines toward evening, and then rises sharply before bedtime (Figure D.7.).

Preventive Countermeasures

- Consider selective half or full shift off following closure to provide recovery opportunity.
- Maintain consistent sleep and wake times throughout the week.
- Maintain similar or identical sleep and wake times on weekend or nonwork days.

Operational Countermeasures

- Caffeine during day, but no later than 4:00 p.m.
- Strategic naps (on the job) to reduce impact of restricted sleep.
- Consume caffeine just before strategic naps to counteract sleep inertia on waking.
- Self-selected rest breaks to reduce fatiguing impacts of monotonous tasks or highly complex tasks.

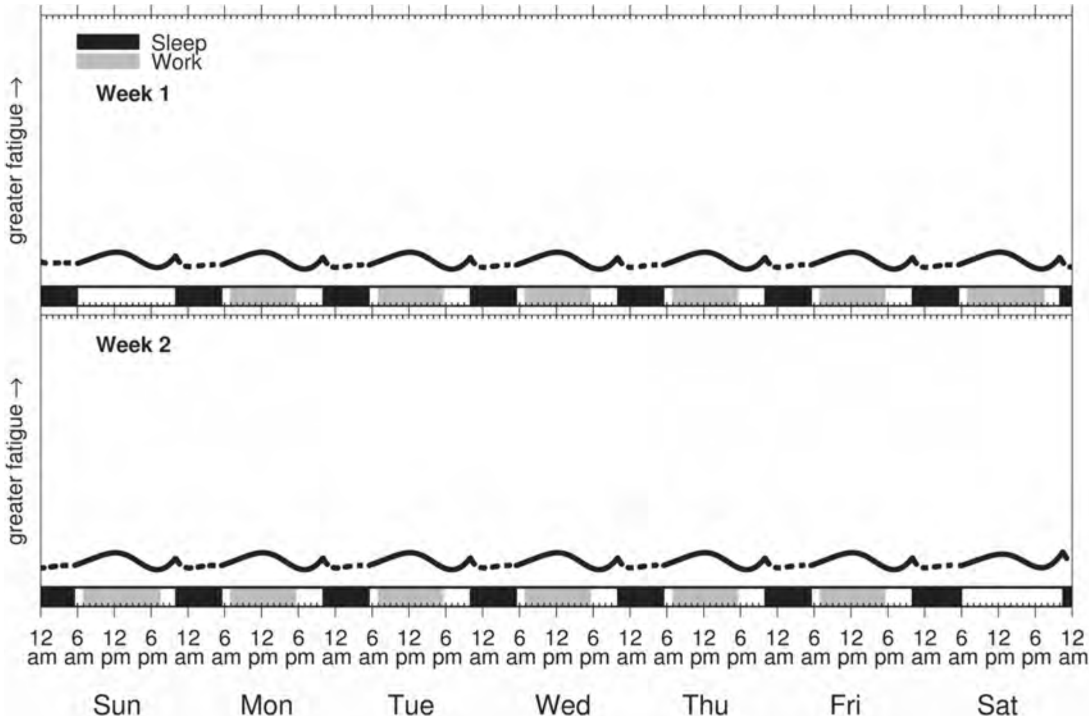


Figure D.7. Fatigue profile: 55-h closure, day-shift schedule.

Comments

- While this example uses a 50-h week as the "base" schedule, the fatigue profile, assumptions, and countermeasures also apply to longer and shorter shift durations within this schedule type.
- With each of the following conditions there is the potential for fatigue to accumulate over time as sleep duration declines:
    - *Shifts that are longer than 10 h* (e.g., during closure) may lead to reduced sleep durations due to a later arrival time home and the need for additional time for personal activities.
    - *Shifts that begin before 7:00 a.m.* may lead to reduced sleep durations because individuals may not be able to compensate for an earlier wake time by going to bed earlier.
    - *Commute times longer than 1 h each way* may lead to reduced sleep durations due to both an earlier wake time and a later arrival time home.

55-Hour Weekend Closure, Night Shift

Night Shift, 50-h week Base Schedule, Monday Night Start

(4 nights × 10 h per night 1st week, 3 nights × 12 h per night on weekend, 5 nights × 10 h per night second week, for 12 consecutive nights worked)

Application

Accelerated schedules, nighttime portion of two-shift continuous construction (7-h urban night closure during week) with break for evening rush-hour traffic during the week, switching to 12-h shifts for closure period. Used with 55-h (10:00 p.m. Friday to 5:00 a.m. Monday) weekend closure.

Shift Start Day:	Mon.–Thur. Week 1	Fri.–Sun. (closure)	Mon.–Fri. Week 2
Shift Start Time:	8:00 p.m.	7:00 p.m.	8:00 p.m.
Shift End Time:	6:30 a.m.	7:30 a.m.	6:30 a.m.
Bedtime, After Shift:	8:30 a.m.	9:30 a.m.	8:30 a.m.
Wake Up, After Shift:	1:00 p.m.	1:00 p.m.	1:00 p.m.
Total Sleep, After Shift:	4.5 h	3.5 h	4.5 h

Assumptions

- 30-min meal break
- 1-h commute
- 1 h of "down time" between arriving home after work and going to bed
- 1:00 p.m. wake time

Fatigue Profile

Fatigue level rises steeply throughout the shift and commute home to a maximum just before going to bed. Peak fatigue increases each shift until early Saturday morning. Very high fatigue levels during shifts are primarily the result of being awake during a phase in the circadian cycle when there is substantial pressure to sleep. The progressive increase in overall fatigue throughout the week (cumulative fatigue) is the result of sleep loss while working night shift. Sleep durations are significantly shorter than for day shifts because of circadian rhythm influences: for shifts ending at 7:30 a.m., a maximum sleep duration of 3.5 h due to circadian pressure to wake around 1:00 p.m. (Figure D.8.).

Preventive Countermeasures

- Minimize use of extended shifts (10 to 12 h) due to reduced individual crew recovery opportunities.
- Consider selective half or full shift off following closure to provide recovery opportunity
- Defensive nap in the afternoon before beginning night shift.
- Return to day schedule (sleeping at least 8 h per night) on days off, following a morning nap on 1st day off from nights.
- Sleep in on the weekend to make up for sleep loss during the week.

Operational Countermeasures

- Caffeine during the shift, but no later than 5 h before bedtime.
- Strategic naps (on the job) to reduce impact of shortened sleep periods. A mid-shift nap substantially reduces peak fatigue within and across shifts and reduces cumulative fatigue.
- Consume caffeine just before strategic naps to counteract sleep inertia on waking.
- Self-selected rest breaks to reduce fatiguing impacts of monotonous tasks or highly complex tasks.
- Supervisory monitoring for signs of fatigue and application of countermeasures.

Comments

- While this example uses a 50-h week as the "base" schedule, the assumptions and countermeasures also apply to longer and shorter shift durations within this schedule type. *Peak fatigue levels and cumulative fatigue effects* will vary with shift end time, but the same general pattern holds for all night shift variations.
- With each of the following conditions there is the potential for fatigue to accumulate over time as sleep duration declines:
    - *Shifts that end later than 4:00 a.m.* will lead to reduced sleep durations due to circadian pressure to wake around 1:00 p.m. Longer night shifts tend to end later, resulting in later bedtimes; long night shifts should be used sparingly.
    - *Commute times longer than 1 h each way* may lead to reduced sleep durations due to a later bed time.
- *Returning to a day schedule on days off* may not substantially increase sleep duration compared with staying on a night schedule, but it is likely to result in improved sleep quality and less disruption to daily activities.

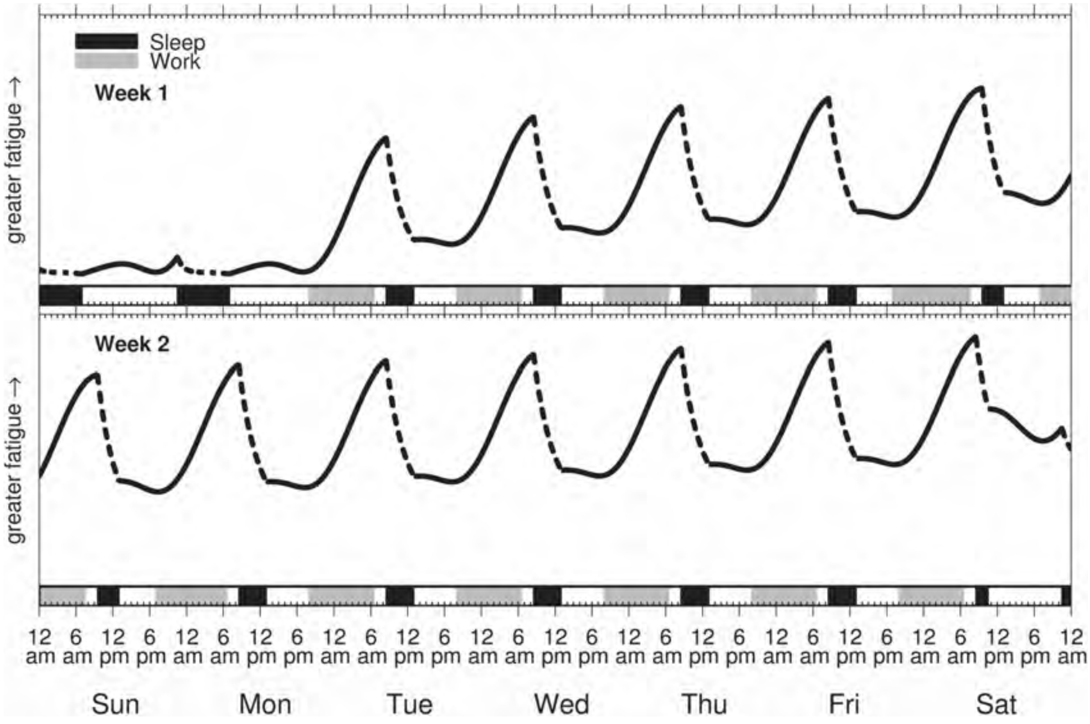


Figure D.8. Fatigue profile: 55-h closure, night-shift schedule.

Switching (Rotating) Shifts

Switching Day Shift to Night Shift Over Weekend, 50-h Week

(5 shifts × 10 h per shift, 2 weeks)

Application

Used for crew skill mix and schedule management as required (in this example, with 7-h urban closures at night).

Day Shift, Week 1		Night Shift, Week 2	
Shift Start Time:	7:00 a.m.	Shift Start Time:	8:00 p.m.
Shift End Time:	5:30 p.m.	Shift End Time:	6:30 a.m.
Bedtime:	10:00 p.m.	Bedtime, After Shift:	8:30 a.m.
Wake Up:	5:30 a.m.	Wake Up, After Shift:	1:00 p.m.
		Total Sleep, After Shift:	4.5 h

Assumptions

- All shifts:
  - 30-min meal break
  - 1-h commute
- While on day shift:
  - 7.5 h of sleep nightly
  - 30 min of personal time between waking up and starting work
- While on night shift:
  - 1 hour of "down time" between arriving home after work and going to bed
  - 1:00 p.m. wake time

Fatigue Profile

While on day shift (Week 1), fatigue peaks just after noon, declines toward evening, and then rises sharply before bedtime; 7.5 h sleep each night allows full recovery each day. While on night shift (Week 2), fatigue level rises steeply throughout the shift and commute home to a maximum just before going to bed. Peak fatigue increases each shift until early Saturday morning. Very high fatigue levels during night shifts are primarily the result of being awake during a phase in the circadian cycle when there is substantial pressure to sleep. The progressive increase in overall fatigue throughout Week 2 (cumulative fatigue) is the result of sleep loss while working night shift. Sleep durations are significantly shorter than for day shifts because of circadian rhythm influences: for shifts ending at 6:30 a.m., a maximum sleep duration of 4.5 h due to circadian pressure to wake around 1:00 p.m. (Figure D.9.).

Preventive Countermeasures

- Minimize use of extended shifts (10 to 12 h) at night due to reduced individual crew recovery opportunities. Consider reduced shift duration, for example, 8 h for night shift after switching.

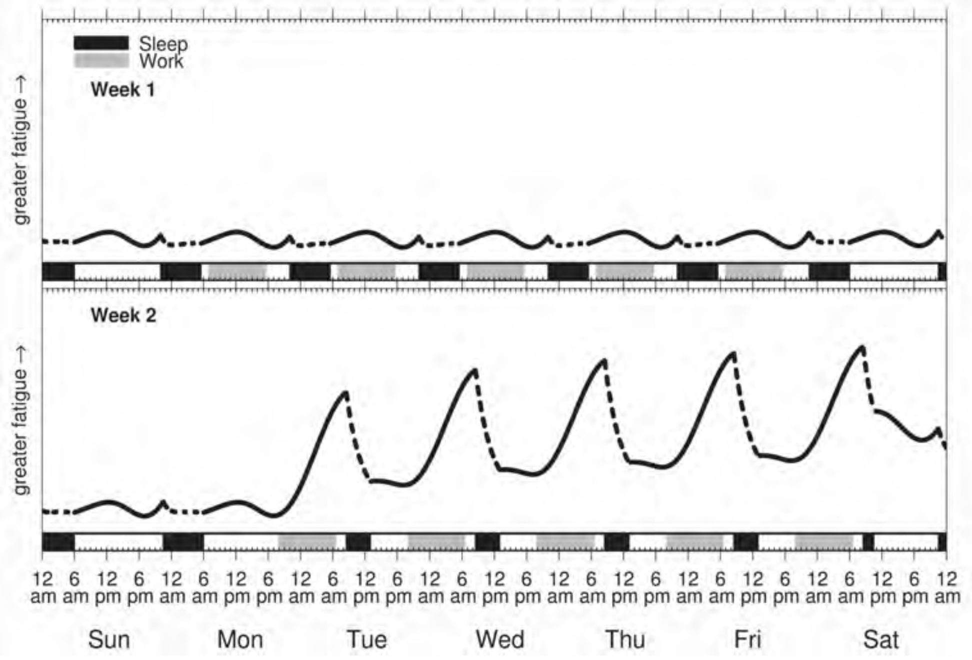


Figure D.9. Fatigue profile: switching from day shift to night shift over a weekend.

- When switching shifts midweek, avoid using double shifts, that is, provide at least a 24-h break between shifts.
- Take defensive nap in the afternoon before beginning night shift.
- Return to day schedule (sleeping at least 8 h per night) on days off, following a morning nap on 1st day off from nights.
- Sleep in on the weekend to make up for sleep loss during the week.

Operational Countermeasures:

- Caffeine during shift, but no later than 4:00 p.m. (days) or 5 h before bedtime (nights).
- Strategic naps (on the job) to reduce impact of shortened sleep periods (nights) or restricted sleep (days).
- Consume caffeine just before strategic naps to counteract sleep inertia on waking.
- Self-selected rest breaks to reduce fatiguing impacts of monotonous tasks or highly complex tasks.
- Supervisory monitoring for signs of fatigue and application of countermeasures.

Comments

- While this example uses a 50-h week as the "base" schedule, the assumptions and countermeasures also apply to longer and shorter shift durations for both day and nights shifts, respectively. *Peak fatigue levels and cumulative fatigue effects* on night shift will vary with shift end time, but the same general pattern holds for all night-shift variations.
- Switching from nights to days over a weekend involves reversing the schedule and wake and sleep times shown in this scenario. This direction of switching is much easier for workers, although there will be some residual cumulative fatigue that is resolved throughout the week as they obtain more restorative sleep during 7.5 h episodes.
- With each of the following conditions there is the potential for fatigue to accumulate over time as sleep duration declines:
    - *Day shifts that are longer than 10 h* may lead to reduced sleep durations due to a later arrival time home and the need for additional time for personal activities.
    - *Day shifts that begin before 7:00 a.m.* may lead to reduced sleep durations because individuals may not be able to compensate for an earlier wake time by going to bed earlier.
    - *Night shifts that end later than 4:00 a.m.* (see variations) will lead to reduced sleep durations due to circadian pressure to wake around 1:00 p.m. Longer night shifts tend to end later, resulting in later bedtimes; long nights shifts should be used sparingly.
    - *Commute times longer than 1 h each way* may lead to reduced sleep durations due to both an earlier wake time and a later arrival time home.

- *Returning to a day schedule on days off* may not substantially increase sleep duration compared with staying on a night schedule, but it is likely to result in improved sleep quality and less disruption to daily activities.

Manager, Weekend Closure

Manager Anchor Sleep ("Split") Schedule over 55-h Weekend Closure

With significant night-shift and day-shift presence (2 weeks)

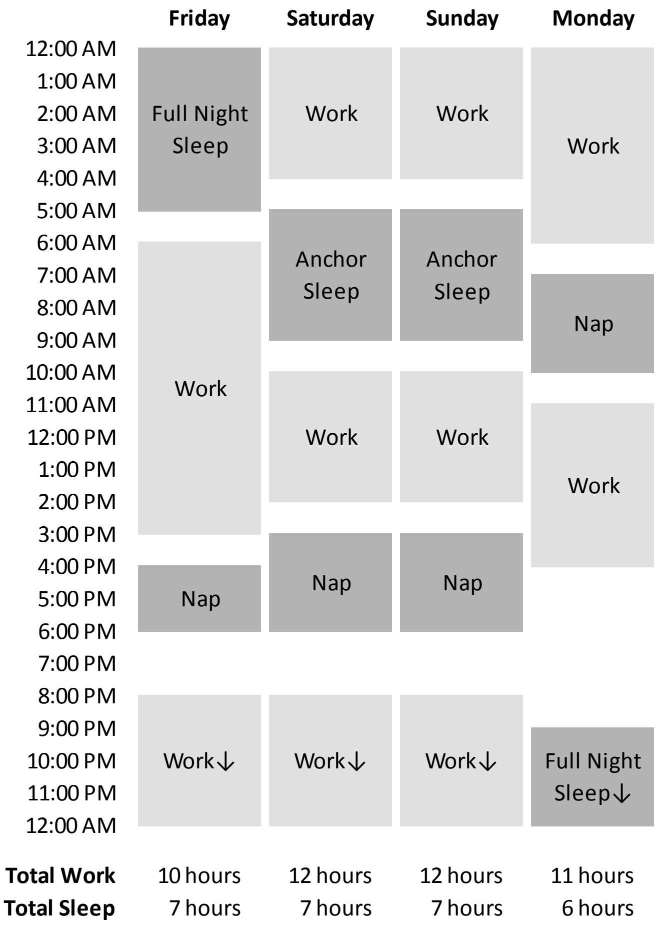
Application

Accelerated schedules requiring manager presence during 55-h (10:00 p.m. Friday to 5:00 a.m. Monday) weekend closure.

Base 50-h week schedule before and after weekend closure

Shift Start Time:	7:00 a.m.
Shift End Time:	5:30 p.m.
Bedtime, Work Nights:	10:00 p.m.
Wake Up, Workdays:	5:30 a.m.

Weekend closure schedule



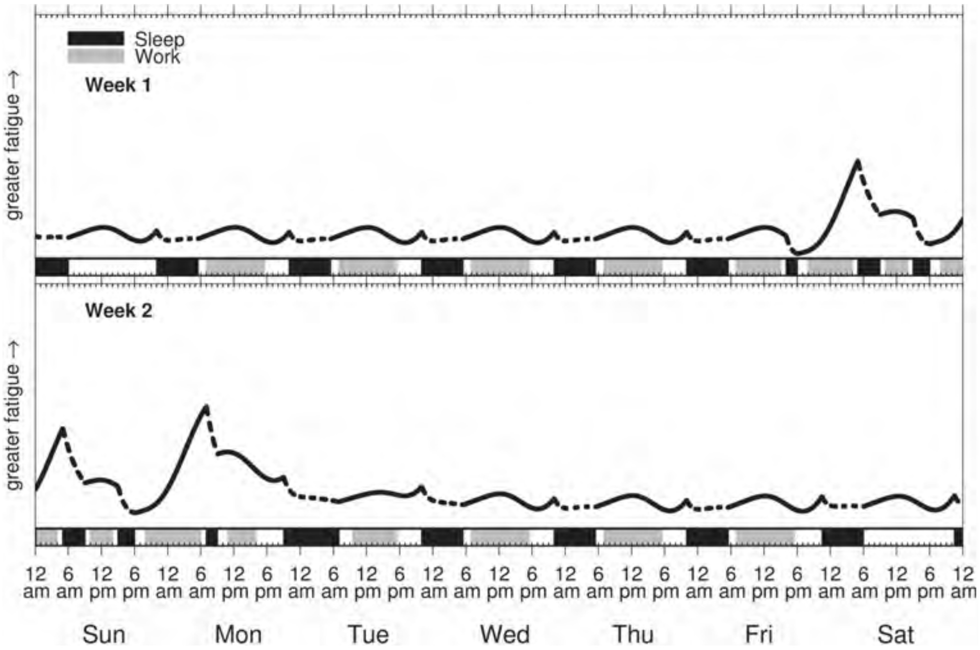


Figure D.10. Fatigue profile: manager anchor sleep schedule for a 2-week period that includes a 55-h weekend closure.

Assumptions

- 1-h commute
- 7.5 h of sleep nightly during regular work week

Fatigue Profile

Managers may feel they need to maintain a presence on the job site for as much as possible of the closure weekend. The primary obstacle to getting sufficient rest may be going to bed in a timely manner once off work. While working during the day ("regular" schedule), fatigue peaks just after noon, declines toward evening, and then rises sharply before bedtime; 7.5 h sleep each night allows full recovery each day. While working during the night (closure period), fatigue level rises steeply throughout the work period to a maximum just before going to bed. Peak fatigue increases for each period of work at night. Very high fatigue levels during night work are primarily the result of being awake during a phase in the circadian cycle when there is substantial pressure to sleep. The progressive increase in overall fatigue throughout the closure period (cumulative fatigue) is the result of sleep loss while working at night. However, anchor sleep periods maintain relatively low baseline fatigue levels overall, allow for 11 to 12 h of work daily during closure period, and allow for good fatigue recovery in the subsequent week (Figure D.10.).

Preventive Countermeasures

- Use anchor sleep to obtain 6 to 8 h in two separate sleep periods as the primary countermeasure.
- Consider selective half or full day off following the weekend closure to provide recovery opportunity.

Operational Countermeasures

- Caffeine during day, but no later than 5 h before bedtime.
- Strategic naps (on the job) to reduce impact of shortened sleep periods.
- Consume caffeine just before strategic naps to counteract sleep inertia on waking.
- Self-selected rest breaks to reduce fatiguing impacts of monotonous tasks or highly complex tasks.
- Supervisory monitoring for signs of fatigue and application of countermeasures.

Comment

- For additional fatigue profiles, countermeasures, and considerations that are relevant to managers under other conditions, refer to the pages for *Day Shift Schedules* and variations (for "typical" manager schedules) or to the *Designer/Engineer High Production Schedule* (for very long work weeks that include weekend hours).

Designer/Engineer High Production Schedule

Designer/Engineer, 80-h week

(5 days × 14 h per day, 1 day × 10 h per day)

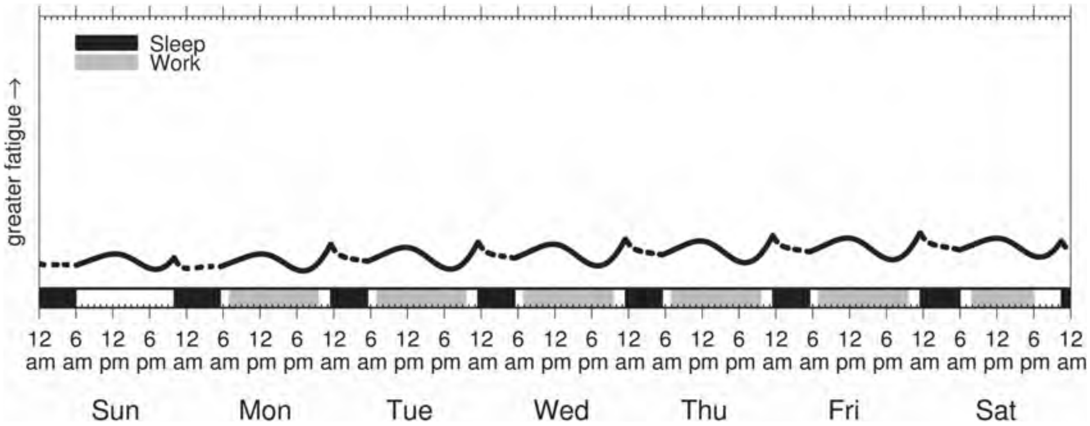


Figure D.11. Fatigue profile: high production (80 h per week) designer schedule.

Application

Approaching deadline on design work prior to construction.

	Mon. to Fri.	Sat.
Shift Start Time:	7:00 a.m.	8:00 a.m.
Shift End Time:	9:30 p.m.	6:00 p.m.
Wake Up:	5:30 a.m.	6:00 a.m.
Bedtime:	11:30 p.m.	10:30 p.m.
Total Sleep Nightly:	6 h	7.5 h

Assumptions

- 30-min meal break
- 1-h commute
- 30 min of personal time between waking up and starting work

Fatigue Profile

Fatigue rises noticeably in the early afternoon, declines toward evening, and then rises sharply and peaks just before bedtime. This pattern is similar to a standard day shift, but the progressive increase in overall fatigue throughout the week (cumulative fatigue) is the result of sleep loss: The 14-h days in this schedule limit sleep to 6 h per night on weeknights (Figure D.11.).

Preventive Countermeasures

- Maintain consistent sleep and wake times throughout the week.
- Sleep in on the weekend or take naps when able to make up for sleep loss during the week.
- Reduce high production designer workload through increased staffing and project planning.

Operational Countermeasures

- Caffeine during day, but no later than 4:00 p.m.
- Strategic naps (on the job) to reduce impact of restricted sleep.
- Consume caffeine just before strategic naps to counteract sleep inertia on waking.
- Self-selected rest breaks to reduce fatiguing impacts of monotonous tasks or highly complex tasks.

Comments

- Each of the following conditions can contribute to even greater fatigue accumulation over time as sleep duration declines:
  - *Late arrival time home and need for additional time* for personal activities can further restrict sleep.
  - *Commute times longer than 1 h each way* may lead to reduced sleep durations due to both an earlier wake time and a later arrival time home.
- For additional fatigue profiles, countermeasures, and considerations that are relevant to designers and engineers under other conditions, refer to the pages for *Day Shift Schedules* and variations (for "typical" designer/engineer schedules).

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Related SHRP 2 Research

Performance Specifications for Rapid Highway Renewal (R07)
Process of Managing Risk on Rapid Renewal Projects (R09)
Project Management Strategies for Complex Projects (R10)
Strategic Approaches at the Corridor and Network Level to Minimize Disruption from the Renewal Process (R11)