Worker Fatigue

Managing concerns in rapid renewal highway construction projects

By Matthew R. Hallowell

HIGHWAY CONSTRUCTION WORK can be demanding and exhausting. It requires intense focus and physical exertion, the use of heavy mobile equipment and repetitive work tasks, and it is performed adjacent to traffic (NIOSH, 2001). These factors all contribute to the relatively high injury rate in the construction sector (BLS, 2007).

Traditionally, roadway construction has been performed during normal, daytime work hours. However, as America's highway infrastructure continues to degrade and congestion becomes an increasing concern, roadways must be renewed quickly.

As a result, rapid renewal strategies such as nighttime work, continuous work, extended shifts and modularization are employed to compress schedules and minimize traffic disruption (Transportation Research Board, 2009). While these strategies enhance overall schedule performance, the associated conditions contribute to worker fatigue, which compounds the safety risk factors inherent to highway construction.

Rapid renewal projects are especially susceptible to two types of fatigue: cognitive fatigue and localized muscular fatigue. Cognitive fatigue is the lassitude of thought and decision processes, while localized muscular fatigue is the reduction in peak tension of a specific muscle group due to prolonged or excessive use.

Researchers have found that conditions in work environments similar to rapid renewal projects contribute to both types of fatigue because construction laborers perform repetitive tasks for extended work shifts and must continuously communicate with the other crew members while performing complex, dynamic and fast-paced work (Sauer, Wastell, Hockey, et al., 2002; Matthews & Desmond, 1998).

However, few available references promote effective fatigue management on con-

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struction projects and no literature focuses on rapid renewal scenarios. This article summarizes the relatively large but disparate body of literature related to mental and localized muscular fatigue and offers a conceptual model for fatigue management on highway construction projects.

Specifically, the focus is on personal and project-related characteristics that contribute to fatigue, methods of measuring fatigue, mitigation strategies, and the impacts of fatigue on safe work behavior and quality of life. Special attention is given to physiological fatigue and localized muscular fatigue on rapid renewal highway projects.

Rapid Renewal

Simply stated, *rapid renewal* means completing highway projects quickly, with minimal disruption to the community and producing facilities that are long lasting. Rapid renewal applies innovative techniques or technologies to reduce the time traditionally allocated to on-roadway activities.

Benefits of this approach include minimizing disruptions to the traveling public, business owners and communities. These benefits are realized in the form of fewer delays, shorter periods with reduced capacity roadways and less construction noise. On the downside, such scenarios may affect worker fatigue and may indirectly compromise worker safety and health, productivity, quality and teamwork. Persons affected may include designers, construction managers, inspectors, laborers and others.

Specific Rapid Renewal Tactics

Some confusion exists regarding the specific tactics that characterize rapid renewal projects. Recently, Transportation Research Board (2009) identified several tactics developed to reduce the time needed to complete on-roadway construction:

- **Perform faster in situ construction** by performing projects on a compressed schedule. To achieve this, contractors extend overtime shifts, mobilize additional workers, and employ innovative technologies and strategic design. This tactic also typically involves the use of design-build project delivery, flexible performance specifications and nondestructive testing.
- **Minimize field fabrication** and maximize prefabrication that can occur off site. This tactic may entail prefabricating units of roadway or bridges, modular construction and innovative installation strategies. Modular and prefabricated elements allow for accelerated schedules, improved quality control and longevity; such techniques also enhance the project's overall level of performance.
- **Perform faster construction inspection and monitoring** by ensuring that renewal projects are inspected and accepted quickly so that they may be reopened to the public.
- **Facilitate innovative and equitable contracting environment** by making decisions and accepting them rapidly. To effectively employ this tactic, risk must be shared among project partners (e.g., DOT agencies, designers, private contractors, partners). Additionally, performance-based specifications must be used to give the contractor control over construction-related risks.
- **Improve customer relations** by recognizing the role that utilities and railroads play in project development and execution. To prevent conflicts, institutional and procedural changes must be made and a proactive strategy for dealing with conflicts must be established early on.

The most common rapid renewal tactics involve the use of management strategies that compress construction schedules. These strategies focus on altering construction means and methods, work shift duration and the intensity of critical phases. As noted, use of these strategies can increase worker fatigue, thereby affecting work zone safety and the workforce's quality of life.

Let's review causal factors of fatigue in general; individual risk factors; immediate effects on safety, health and human error; effects on work performance; long-term effects; methods of measuring fatigue; and known countermeasures.

Occupational Fatigue

Fatigue, defined as lassitude or exhaustion of mental and physical strength resulting from bodily labor or mental exertion, is a concern of workers in many occupations throughout the world. While occupational safety and health has improved in recent decades, fatigue remains a common problem in developed countries (Lewis & Wessely, 1992).

Fatigue is a serious threat to quality of life and severely compromises work performance when it becomes chronic or excessive (Piper, 1989; Okogbaa, Shell & Filipusic, 1994). Unfortunately, its complex and dynamic nature makes fatigue difficult to define, observe and measure. As a result, it has traditionally been excluded by funding agencies and scientific studies, especially in construction.

While few studies have examined fatigue in the construction industry, a wide body of literature describes the general causes and effects of occupational fatigue. It is assumed that research from industries such as manufacturing and transportation apply to the infrastructure construction environment because of the prevalence of repetitive work tasks, use of heavy equipment and complex work processes. That said, some characteristics of construction, such as exposure to the elements and dynamic work environments, may not be adequately modeled in previous research in other industries.

To classify the types of fatigue that occur in occupational environments, Bills (1934) established definitions and distinctions for three types of fatigue: physiological (reduction of physical capacity), objective (reduction in work) and subjective (feelings of weariness). Secondary aspects of fatigue include sleepiness (Gillberg, Kecklund & Akerstedt, 1994), discomfort, and weakened activation and weakened motivation (Kashiwagi, 1969).

These essential studies provide the framework for fatigue research and for the development of objective

Abstract: *Construction strategies that minimize congestion and disruption to local communities are becoming more common. These rapid renewal strategies involve extended work shifts, nighttime work and work zones adjacent to active roadways. Since rapid renewal will likely add to occupational fatigue on highway construction sites, managers must understand occupational fatigue to successfully deliver projects with minimal injuries. This article reviews characteristics that contribute to cognitive and localized muscular fatigue, methods to measure and control fatigue and its effects on safe work behavior and quality of life. A model of fatigue management is offered as well.*

measures. While little fundamental or transformative research has been performed in recent decades, many studies have refined this fundamental body of literature and have explored fatigue in specific industries and emerging work scenarios (Leung, Chan, Ng, et al., 2006; Jansen, van Amelsvoort, Kristensen, et al., 2003; Ashburg, Gamberale & Kjellberg, 1997).

Causal Factors

Various factors can contribute to cognitive and localized physical fatigue, including specific occupational activities, recreational activities, personal characteristics, drug use, sleep deprivation and physical condition. Managers must understand the signals of these types of fatigue as a careful analysis can identify high-risk individuals and work environments. While many factors affect fatigue, the three major factors related to rapid renewal highway projects are shift work, extended work shifts and work time control.

During rapid renewal projects, workers often must adapt to new work shifts, extended shifts and high intensity work. While the effects of such transitions have yet to be explored in the construction industry, a large body of literature discusses the effects of shift work on fatigue in manufacturing settings. It is expected that many of these underlying principles apply to rapid renewal highway projects despite the obvious differences between manufacturing and construction.

Findings from several fundamental studies are concisely presented as follows:

- Andlauer (1960), Bruusgaard (1969) and Akerstedt (1988) estimated that about 20% of the worker population is unable to adapt to shift work.
- Adaptation to shift work occurs more easily and more often in "stabilized" rather than "rotating" shifts (Colquhoun, 1971).
- Well-adapted shift workers show significantly less psychosomatic tension than poorly adapted workers (Hakkinen, 1969).
- Frequent alternation of shifts on continuous work was preferred to the commonly used 1-week spells, due to reduced experience of fatigue and monotony (Walker, 1966).
- Workers on continuous alternating shifts starting at the hours 4-12-20 obtained more sleep than after a change to 6-14-22 (Bjerner, Holm & Swensson, 1948).
- When compared with the 6-14-22 system, the 7-15-23 system results in fewer accidents and greater productivity (Oginski, 1966; Wild & Theis, 1967).
- Fatigue is reduced when shifts occur in the order night-evening-day, instead of the more common day-evening-night pattern (Saito & Kashiwagi, 1970).

Most of this foundational work was conducted in the mid-20th century. Researchers have more recently investigated fatigue in complex and emerging environments such as high-speed maritime operations (Leung, et al., 2006), aviation and aerospace (Folkard & Akerstedt, 2004).

Review of this fundamental literature indicates that work shift design may significantly affect the potential for fatigue that the construction industry must recognize. Many individual factors, such as age, health and living conditions, influence a worker's ability to adapt to shift work or changes in shift sequences, timing or duration. Likewise, extended work shifts and overtime introduce unique fatigue issues. Shift design strategies are essential to preventing both mental and localized physical fatigue.

Long work hours are common in every major U.S. industry, including construction. In fact, more than one-quarter of U.S. men and 11% of women work more than 50 hours a week (Jacobs & Gerson, 2004). In this context, extended work shifts and the term *overtime* refer to a prolonged investment of effort (by individual or crew) where recovery time is reduced.

The effect of extended work shifts is highlighted because long working hours can negatively affect workers' health and well-being (Sparks, Cooper, Fried, et al., 1997; van der Hulst, 2003). Overtime work can lead to a situation of prolonged, insufficient recovery that is assumed to disturb physiological processes and, as a consequence, induce health problems (Geurts & Sonnentag, 2006).

However, the association between overtime and well-being depends on the psychosocial profile of the overtime job (Beckers, van der Linden, Smulders, et al., 2004). For example, van der Hulst (2003) shows that moderate overtime hours were only related to fatigue in cases of high job demands in combination with low autonomy.

Not all workers report ill effects from working extended periods. In fact, multiple individual characteristics, such as strong physical condition, allow some to better adjust to extended work periods. Interestingly, two psychosocial work characteristics have been found to influence overtime's effect on fatigue and worker health: 1) control over overtime work; and 2) rewards for overtime work (Harma, 2006). Work time control has been defined as "an employee's possibilities of control over the duration, position and distribution of work time" and reward systems include compensation for working extended hours (Harma).

Involuntary overtime work is associated with relatively high fatigue and low satisfaction, especially for involuntary overtime workers without rewards (Beckers, et al., 2004). Fenwick and Tausig (2001) found that lack of schedule control is associated with work-home interference, burnout symptoms, distress, dissatisfaction, poor general health and minor physical problems.

A series of longitudinal studies found that low work time control increases the risk of health problems, whereas high control over working time reduces the adverse effect of work stress on sickness absence and can help employees establish an appropriate work-life balance (Ala-Mursula, Vahtera, Kivimaki, et al., 2002; Ala-Mursula, Vahtera, Pentti, et al., 2004; Ala- Mursula, Vahtera, Linna, et al., 2005; Ala-Mursula, Vahtera, Kouvonen, et al., 2006).

Tucker and Rutherford (2005) found overtime work to be related to impaired health only among respondents who worked overtime in response to pressure (i.e., low overtime control) and who lacked social support. Voluntary overtime workers in comparable positions were nonfatigued and satisfied, even without rewards.

Rewards for overtime work (e.g., receiving or not receiving compensation for extra work hours) constitute another psychosocial work characteristic that may act as a moderator in the overtime/well-being association. The importance of rewards follows from the effort-reward imbalance (ERI) model (Siegrist, 1996; 1998). This theory states that employees' efforts at work are part of a social exchange process in which employees expect fair rewards or compensation for their invested efforts. Therefore, it may be concluded that control of overtime is important for well-being and that the negative effects of compulsory overtime may be partly offset by fair compensation for the extra work (Beckers, et al., 2004).

Individual Risk Factors

All workers have unique physical conditions, intellectual abilities and emotional stability. These characteristics are manifested in the ability to adapt to extended work periods and rotating shifts, tolerance of fatigue and effects of fatigue. Age is one of the most influential factors. Thüs-Evensen (1958) recommended that workers over age 50 with no previous shift work experience be rejected because of their susceptibility to muscular fatigue. Menzel (1962) added that workers younger than age 25 are at high risk for cognitive fatigue, especially if they have to provide their own meals.

Mott, Mann, McLoughlin, et al. (1965), concluded that adapting to shift work is more difficult for younger, better educated workers who have small children, while men who could work additional jobs ("moonlighters") seldom complained about the adaptation of their time-oriented body functions. This implies that some workers may be resistant to cognitive fatigue.

Literature has consistently shown that nearly all workers are vulnerable to localized muscular fatigue when performing repetitive tasks for extended periods. McGirr (1966) notes several conditions that should preclude employees from alternating shift work such as a need for continuous drug therapy; epilepsy or diabetes; serious gastrointestinal diseases (e.g., ulcer and colitis); heart and circulatory diseases; and marked stress and anxiety syndromes.

Many studies have also found that circadian rhythms can affect a worker's ability to adapt. Patkai (1971) studied habitual "morning" and "evening" workers and found many significant differences in alertness, performance and adrenal excretion. She found that habitual working habits might be an important factor in determining both efficiency of performance and work satisfaction.

Ostberg (1973) estimated that the morning types are approximately 2 hours ahead of the evening types in the circadian rhythms of oral temperature and food intake. Finally, Aanonsen (1964) found that a high proportion of workers who had transferred to nonshift work for medical reasons were the early-to-bed/early-to-rise type. Table 1 presents a summary of the leading indicators for cognitive and localized muscular fatigue. Some factors are unique to either cognitive or muscular fatigue, while other factors, such as extended work periods and heat, contribute to both.

Table 1

Leading Indicators for Fatigue

Causal factors	Individual risk factors
Long work hours (overtime)	Unsatisfactory housing conditions
Job with low autonomy	> 50 years of age
Psychosocial profile of the work	< 25 years of age
Low job satisfaction	Workers who must provide their own meals
Low control over overtime	Need for drug therapy
Extended work periods	Epilepsy
Noise	Diabetes
Heat	Gastrointestinal diseases (ulcers, colitis)
Repetitive work tasks	Heart/circulatory diseases
Tasks that lead to a higher VO2Max	Stress/anxiety syndromes
	Workers with young children
	Early-to-bed/early-to-rise
	Introverts
	Nonrobust individuals
	Ill-adapted individuals

Some leading indicators for cognitive and localized muscular fatigue are unique to either cognitive or muscular fatigue, while other factors, such as extended work periods and heat, contribute to both.

Measuring Fatigue

Researchers often report that they omit fatigue in occupational safety and health studies because it is difficult to measure and track fatigue in dynamic work environments. In the past decade, several methods for measuring fatigue have been developed, validated and vetted by the research community. Of these methods, the Swedish Occupational Fatigue Inventory (SOFI) and the similar CIS20R appear in most peer-reviewed academic publications that attempt to measure fatigue in an occupational setting.

Other measurement methods have been developed as well, but they have little application to occupational settings. For example, the use of VO2Max testing (i.e., a measure of oxygen uptake by the human body that measures aerobic capacity) would be impractical in a rapid renewal environment as it is intrusive, limits workers' ability to remain productive and may extend work periods even further.

To simultaneously evaluate the intensity and quality of perceived fatigue, several scales have been developed (Kinsman & Weiser, 1976). These dimensions have been labeled as lack of energy, physical exertion, physical discomfort, lack of motivation and sleepiness. The underlying structure of the instrument corresponds to a qualitative and quantitative description of the physical (exertion and discomfort) and mental (lack of motivation and sleepiness) dimensions of perceived fatigue.

Originally, the SOFI included 25 expressions (five for each dimension) related to physiological, cognitive, motor and emotional responses (Ashburg, et al., 1997). In most studies, participants were asked to rate on a 25-point scale the extent to which the expressions described their feelings at that moment,

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Figure 1

SOFI Scale

	Not at all		To a very high degree				
	0	1	2	3	4	5	6
Lack of energy							
Worn out							
Spent							
Drained							
Overworked							
Physical exertion							
Palpitations							
Sweaty							
Out of breath							
Breathing heavily							
Physical discomfort							
Tense muscles							
Numbness							
Stiff joint							
Aching							
Lack of motivation							
Lack of concern							
Passive							
Indifferent							
Uninterested							
Sleepiness							
Falling asleep							
Drowsy							
Yawning							
Sleepy							

during the last few minutes, when they were most tired and so on to quantify their relative level of fatigue.

The SOFI scale has been refined and validated for occupations such as teachers, firefighters, cashiers, bus drivers and engineers. Internal consistency of the subscales was satisfactory, with Cronbach's alphas above .80, especially for lack of energy (.92); lack of motivation (.92); sleepiness (.89); physical discomfort (.81); and physical exertion (.87). It should be noted that these scales measure whole body fatigue which includes most subsets of fatigue such as psychological fatigue, sleepiness and loss of motivation (e.g., burnout) in addition to those types highlighted in this article. Figure 1 presents the SOFI scale.

Effects of Fatigue

Safety & Work Performance

The effects of cognitive and muscular fatigue on individual workers can cause immediate reductions in safe work behavior, productivity, teamwork and morale. Goldenhar, Hecker, Moir, et al. (2003), found that excessive overtime both within 1 day and across many days adversely affects productivity and that worker productivity was affected by the manner in which overtime jobs were run in terms of timelines and type of supervision. Goldenhar, et al., also observed that injury frequency and severity increases during extended periods of work, sometimes dramatically due to an increase in human error caused by lassitude in cognitive processes. These observations were strictly qualitative as no attempt was made to measure productivity.

Human Error

To better understand the relationship between fatigue and safe work behavior, let's examine the potential effects of cognitive fatigue on human error. While these may seem like disparate topics, accidents, rework, conflicts and decreases in productivity involve some element of human error. According to fundamental social psychology literature summarized by Reason (1990), these errors are caused by deficiencies in mental function that are accelerated as mental and physical fatigue increase. The sidebar below lists the immediate effects of fatigue.

Errors in judgment, decision making and physical actions result in loss of productivity, the need for rework in industrial operations and occupational injuries. To prevent human error, organizations conduct training, provide feedback to workers and perform inspections (Hinze, 2006). These activities rarely involve methods to reduce or even address cognitive fatigue despite its obvious effect on thought processes.

Error Types & Potential Controls

To target human error, the various modes by which it occurs and the contribution of fatigue to each mode must be explored. According to Reason (1990), human error occurs in a limited number of forms. These include intentional erroneous actions (mistakes and violations) and unintentional erroneous actions (slips and lapses). The fundamental difference between these is that mistakes are planning errors (e.g., intentionally choosing an unsafe pathway through a worksite) while slips and lapses are the result of failures in execution (e.g., inattentiveness, distraction).

Much social psychology literature has attempted to define error types and potential controls. Let's briefly discuss this body of literature.

Reason (1990) defines mistakes as "deficiencies or failures in the judgmental and/or inferential process involved in the selection of an objective or in the specification of the means to achieve it, irrespective of

Immediate Effects of Fatigue on Humans

- Reduction in physical capacity (weakness)
- Reduction in work
- Mistakes
- Slips
- Lapses
- Weariness
- Memory loss
- Sleepiness
- Discomfort
- Weakened motivation
- Irritability
- Illness

Table 2

Human Error, Work Environment & Impacts

Human error	Definition	Susceptible environments	Impact of cognitive fatigue
Mistakes	Intentional planning related error (e.g., skill-based errors)	Dynamic work environments are prevalent and standardized work processes do not ensure sufficient worker-hazard interactions	Mistakes become more common as workers' judgment deteriorates during extended periods of work and mistakes remain undetected due to supervisor fatigue
Slips	Unintended erroneous actions that result from mental distractions in familiar work environments	Typical work environments with one or more unusual external distractions	Distractions have a greater effect as workers have increasing difficulty focusing on their work tasks
Lapses	Unintended erroneous actions that result from temporary memory failure	Typical work environments	Memory failures increase dramatically during periods of mental fatigue

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whether or not the actions directed by this decision scheme run according to plan." According to Rasmussen, Pejtersen and Goldstein (1994), mistakes are relatively common and exist in two categories: knowledge-based or rule-based. Rule-based mistakes involve the intentional application of a bad rule. These mistakes result from errors in standardized procedures and reflect deficiencies in management.

Reason (1990) defines slips and lapses as "errors which result from some failure in the execution and/or storage stage of an action sequence, regardless of whether or not the plan which guided them was adequate to achieve its objective." These errors occur when workers fail to make a cognitive attentional check because 1) the process or behavior is not habitual (strong habitual intrusions); 2) a distraction prevents one from making required checks (omission); 3) failures of prospective memory prevent safe work procedures (reduced intentionality); or 4) workers inadequately estimate durations within a sequence of actions (mistimed checks). These unintentional errors are differentiated into two categories, those caused by distractions in a familiar work environment (slips) and memory failures (lapses).

Knowledge-based errors are not likely to be largely affected by fatigue unless safety training and orientation meetings are conducted at times when workers are at risk of being fatigued because knowledge-based errors occur when employees do not know or understand the correct methods of performing the work. Mental fatigue is likely to have a significant impact on slips and lapses because these errors are generally caused by errors or inefficiencies in cognitive processes during specific instances in time.

Typically, errors are detected through formal processes in the human body (i.e., self monitoring). Humans constantly check their surroundings to ensure that actions match intent. As cognitive fatigue increases, workers' ability to rapidly perform these mental checks decreases and the speed at which decision processes are executed is reduced.

According to Reason (1990), attention can only be directed to a small part of a total space in any given time and such attention must be focused on important problem spaces to prevent accidents. Such focus decreases substantially as workers become mentally fatigued. Table 2 provides simple definitions of the three human error modes, the environments in which they typically occur, and the effects of cognitive fatigue on each error mode; it is based on social psychology research conducted by Searle (1980) and Mandler (1975).

According to this literature, mistakes, slips and lapses cause accidents because they result in a worker's failure to perceive that an event has occurred (e.g., that a bulldozer has begun to mobilize); failure to diagnose the nature of an event and to determine the necessary remedial actions (e.g., failure to recognize the need to change physical location when a bulldozer's track has broken); and failure to implement those responses in a timely manner. In all cases, mental fatigue increases the potential for human error in occupational environments.

Impact of Fatigue on Quality of Life

While no studies directly associate cognitive or localized muscular fatigue to quality of life, a well-established body of literature links the whole body (i.e., general fatigue) to several ill personal effects. As noted, little is known about the immediate effects of fatigue on task achievement, work quality or teamwork.

Conversely, a relatively wide body of knowledge is related to the long-term effects of fatigue on workers (i.e., quality of life effects). Sparks, Cooper, Fried, et al. (1997), and van der Hulst (2003) reviewed most studies on long work hours and concluded that such hours can negatively influence health and well-being. Most significantly, overtime work leads to prolonged insufficient recovery that is assumed to disturb physiological processes and, as a consequence, induce health problems (Geurts & Sonnentag, 2006). Andersen (1970) showed that if one did not stop at registered sicknesses but also considered gastrointestinal irregularities and other health defects of limited direct medical significance, one would find negative effects of shift work on health.

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Fatigue has been shown to cause significant and frequent health impacts. Fatigue that results from extended work periods has been linked to adverse behavior and habits such as an unhealthy diet, lack of exercise and smoking, which, in turn, may cause health problems.

Table 3

Lagging Indicators of Fatigue

Effects of fatigue on performance	Quality of life impacts
Reduction in quality	Gastrointestinal irregularities
Reduction in productivity	Coronary heart disease
Increased severity of injuries	Stress
Increased frequency of injuries	Hypertension
	Sleep complaints
	Injuries at home
	Slow recovery from illness
	Unhealthy diet
	Lack of exercise
	Smoking
	Suicide due to overwork
	Cardiovascular disease

frequent health impacts such as coronary disease, hypertension (Dembe, Erickson, Delbos, et al., 2005), diabetes (Harma, 2006), insomnia (Taris, Beckers, Dahlgren, et al., 2007) and injuries (Sparks, et al., 1997) among workers in multiple industries.

Additionally, fatigue that results from extended work periods has been linked to adverse behavior and habits such as an unhealthy diet, lack of exercise and smoking, which, in turn, may cause health problems (van der Hulst, 2003).

Several Japanese studies found that extremely long working hours (systematically working more than 60 hours a week) can have severe effects on health, such as *karoshi* (death from overwork) and *karojisatsu* (suicide due to overwork) (Amagasa, Nakayama & Takahashi, 2005; Kawakami & Haratani, 1999; Nishiyama & Johnson, 1997; Sokejima & Kagamimori, 1998; Uehata, 1991). Lagging indicators of fatigue are summarized in Table 3.

Table 4

Preventive & Management Methods for Fatigue

Preventive measures	Countermeasures for fatigue
Control over overtime	Provide workers with more breaks—approximately 10 to 15 minutes every 2 hours
Rewards for overtime	Allow workers to rest and provide shade or air conditioning
Allow for schedule control	Have food and cold water available for workers and encourage them to remain satiated and hydrated
High work time control	Heighten supervision activities when workers are exposed to heat
Frequent alternation of shifts	Decrease pace in the heat and during extended work periods
4-12-20 or 7-15-23 shifts	Take frequent rest breaks and encourage coworkers to do the same
Stabilize shifts	Self monitor physical and mental fatigue
Job rotation	Ask for help lifting heavy materials and note that strength diminishes with increased fatigue
Reduce frequency of successive high-stress activities	Work with a partner during extended work periods
Begin the workday earlier to reduce heat exposure during summer months	Increase teamwork
Limit the number of consecutive hours and days worked	
“Oversupervise” by reducing the ratio of workers to supervisors	
Increase planning and frequency of safety meetings when workers are being pushed	

Studies have investigated specific countermeasures for fatigue in construction. Goldenhar, et al. (2003), created a list of countermeasures and controls for fatigue.

Fatigue Mitigation Strategies

Based on causal factors and individual risk factors, some potential countermeasures for cognitive and localized muscular fatigue are obvious. They include allowing workers to control their overtime shifts; providing rewards for participating in overtime shifts; and precluding some workers based on age, preexisting conditions and circadian rhythms. Several studies have investigated specific countermeasures for fatigue in construction. Goldenhar, et al. (2003), created a list of countermeasures and controls for fatigue (Table 4).

Other studies have investigated job rotation as a control for both types of fatigue. According to Jonsson (1998), job rotation is a method of rotating workers across various tasks that have different physical and mental demands over time and it is a promising method to manage worker fatigue. Job rotation has been implemented in many settings including refuse collecting (Neter, Wasserman & Kutner, 1990), cashiering and poultry processing (Henderson, 1992).

Jonsson (1998) claimed that this strategy is ideal for construction because it is especially useful for dynamic tasks that require variations in muscular load. Furthermore, job rotation reduces errors and increases employee job satisfaction. Developing a proper job rotation plan involves determining which jobs to include, the rotation sequence and the proper rotation interval (Tharmaphornphilas & Norman, 2004).

A more advanced technique is to rotate workers based on a specific policy, such as choosing not to assign a worker to two stressful tasks in succession (Henderson, 1992). Carnahan, Redfern and Norman

(2000) proposed a method to reduce low back injury in a manual lifting environment by implementing a genetic algorithm to provide multiple good job rotation schedules; they then used a clustering method to determine a general set of rules governing task exposure for each group of workers.

One must note several limitations of job rotation in construction. First, job rotation may not be realistic for some tasks that require a relatively high level of skill. Second, job rotation must be strategic as a poor rotation plan can increase risk for some workers. A poorly designed job rotation plan can actually increase worker stress.

Fatigue Risk Management Model

The body of literature reviewed was compiled to create a model (Figure 2) for fatigue risk management during rapid renewal highway construction projects. Particular attention is paid to leading and lagging factors and the immediate and long-term effects.

This model is intended to be used as a quick reference and summarizes the key points from the literature. It is expected that this model can be used by project managers and safety managers to identify, analyze and respond to fatigue risk factors. The discussions in this article and the numerous references provided can help readers gain a better understanding of fatigue causes, effects and countermeasures.

Conclusions & Recommendations

While numerous studies focus on occupational fatigue, no previous studies have attempted to summarize the literature in a cohesive document to mitigate risks in an emerging work environment. Furthermore, no studies specifically focus on the effects of rapid renewal scenarios or the potential effects of cognitive fatigue on human error.

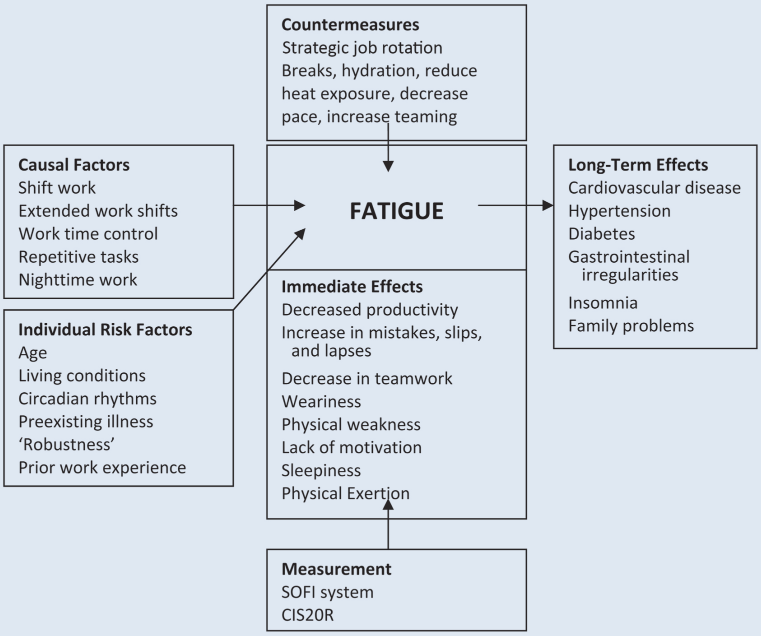
This article provides such a summary and addresses these key points. As this analysis reveals, construction worker fatigue may affect project success and workers' quality of life. Specific controls and countermeasures have been developed in manufacturing, aviation, transportation and healthcare that may have direct application to construction.

The author suggests future research on several topics related to fatigue. First, the effects of construction-specific work tasks on fatigue should be evaluated through objective and rigorous research. Second, the impacts of fatigue on work performance (e.g., productivity and safety) should be measured and compared using activity sampling and safety metrics. Other types of fatigue, such as sleepiness and loss of motivation and concentration, should be highlighted. Finally, the efficacy of the controls noted in this article should be objectively studied.

This article is not intended to be all-inclusive. Rather, the objective was to discuss the various factors that may influence fatigue on rapid renewal highway projects; review the validated methods of measuring fatigue; and highlight how fatigue may influence work performance and quality of life. ■

Figure 2

Fatigue Management Model



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This model is intended to be used as a quick reference and summarizes the key points from the literature. It is expected that this model can be used by project managers and safety managers to identify, analyze and respond to fatigue risk factors.

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