Fatigue Risk Management in the Workplace

ACOEM Presidential Task Force on Fatigue Risk Management:
Steven E. Lerman, MD, MPH, Evamaria Eskin, MD, MPH,
David J. Flower, MBBS, MD, Eugenia C. George, MD,
Benjamin Gerson, MD, Natalie Hartenbaum, MD, MPH,
Steven R. Hursh, PhD, and Martin Moore-Ede, MD, PhD

PURPOSE AND INTRODUCTION

Key Points:

- Fatigue is an unsafe condition in the workplace.
- Like other risk factors, fatigue can be managed.

Safety and productivity in the workplace are intimately related to worker health. A workplace may have chemical, physical, biological, and/or psychosocial hazards that have the potential to impact physical and psychological well-being. How these hazards are managed in the workplace is key. A workplace in which these hazards are well-controlled, with an active culture of health and a supportive work environment, can enhance worker health and well-being, both on and off the job. Healthier employees result in fewer health claims, better safety records, and greater productivity.

Well-rested, alert employees are critical to safe and productive operations. Virtually everyone experiences some level of fatigue from time to time. However, excessive fatigue while working is an important condition in which the interrelationship of health, safety, and productivity can create a vicious or a virtuous cycle. Specific medical and lifestyle interventions have been shown to promote a well-rested and alert workforce. In addition, specific factors in the organization of work have been shown to promote either alertness or fatigue.

Because of the potential impact of fatigue on health, safety, and productivity, any organization in which individuals work extended hours or hours during which people typically sleep can benefit from addressing fatigue in the workplace. This is particularly important for safety-sensitive operations such as the transportation, health care, and energy industries.

Occupational and environmental medicine (OEM) physicians, whether directly employed by or serving as a consultant to an organization, have an important role to play in fatigue risk management. Where no program is currently in place, OEM physicians can and should advise management of the opportunities to enhance health, safety, and productivity through the development of a fatigue risk management system (FRMS). Where an FRMS is in place or under development, OEM physicians can and should play an active role in its development, implementation, and sustainability.

The purpose of this article is to provide information to assist OEM physicians in these roles. It is designed to provide background, key concepts, and references needed to promote and support an FRMS. It is not intended to be a complete "how to" guide in this area. Design and implementation of a comprehensive FRMS requires a wide range of skills, backgrounds, and resources. Many of these resources may be available within an organization; however, it is likely that some will not be available in-house and will need to be contracted out. However, ownership must reside with senior management to ensure a sustained effort. Ergo, the role of the OEM physician to inspire and participate in the development and implementation of an FRMS can be key to a successful program.

THE RISK OF EMPLOYEE FATIGUE IN THE 24/7 WORKPLACE

Key Points:

- Fatigue is related to duration of sleep and timing (circadian rhythm) of sleep.
- Inadequate sleep is correlated with a variety of adverse medical outcomes.
- Various shift work schedules can affect both the duration and the timing of sleep.
- Inadequate duration of sleep is correlated with injury rate.

Difference Between Fatigue and Sleepiness

When the term fatigue is used, many think of it as the same as sleepiness, but these are actually two different (although related) states. Sleepiness is the tendency to fall asleep; fatigue is the body's response to sleep loss or to prolonged physical or mental exertion. Fatigue may be *reduced* by sedentary activity or rest without sleeping, whereas subjective sleepiness and the propensity for sleep are often *exacerbated* by sedentary activity or rest.[1] Sleep propensity can be accompanied by decreased alertness which then leads to decreased attention to detail, impaired judgment, and slowed response time. This can affect productivity, safety, and overall health. Table 1 lists several factors that can lead to fatigue and increased sleep propensity and that affect the resultant degree of impairment.

Fatigue and decreased alertness resulting from insufficient or poor quality sleep can have several safety-related consequences, including slowed reaction time, reduced vigilance, reduced decision-making ability, poor judgment, distraction during complex tasks, and loss of awareness in critical situations. Sleep deprivation has long been recognized as an unmet public health challenge.[2–4] Many individuals believe they adapt to chronic sleep loss or that recovery requires only a single extended sleep episode, but studies have shown that this is not the case.

Science of Sleep, Circadian Rhythms, and Fatigue

Two key contributors to fatigue are insufficient sleep and disruptions in normal sleep cycle. Most individuals will go through several cyclic sleep stages, each cycle about 90 minutes in length, during each sleep period. Disruption of the sleep cycle by shortening or even eliminating some stages can lead to fatigue and its attendant consequences. Sleep stages are identified and evaluated through the use of electroencephalography. There are five basic sleep stages with stages 1 to 4 comprising non-rapid eye movement

TABLE 1. Fatigue Risk Factors

- Sleep deprivation
- Circadian variability
- Time awake
- Health factors (sleep disorders, medications)
- Environmental issues (light, noise)
- Workload

This guidance article was prepared by the American College of Occupational and Environmental Medicine's Task Force on Fatigue Risk Management. The authors and members of the Task Force are Steven E. Lerman, MD, MPH, Evamaria Eskin, MD, MPH, David J. Flower, MBBS, MD, Eugenia C. George, MD, Benjamin Gerson, MD, Natalie Hartenbaum, MD, MPH, Steven R. Hursh, PhD, and Martin Moore-Ede, MD, PhD.

Address correspondence to ACOEM: info@acoem.org.

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sleep, and stage 5 rapid eye movement sleep (characterized by rapid eye movements). Most individuals require between 7 and 8 hours of sleep per night to be fully alert, although some require only 6 hours, and others may require as many as 10 hours per night.

When considering health, safety, and productivity, what seems to be as important as duration and quality of sleep is the time when an individual's intrinsic circadian rhythm sleep occurs. Humans operate on a daily cycle (a circadian rhythm) that is generated from within the suprachiasmatic nucleus[5] and is generally slightly longer than 24 hours, but can vary from individual to individual. Sleep drive (the urge to sleep) increases late at night and reaches a peak in the early morning hours. There is also a small increase in sleepiness in the early to midafternoon. Figure 1 depicts the circadian rhythm showing when sleepiness tends to be at its peak and nadir.[6] Circadian signals control not only daily rhythms in sleep and alertness, but also core body temperature and secretion of some hormones. These rhythms persist in the absence of environmental time cues; however, they can be affected by environmental cues such as light or dark and by when these cues occur (eg, light early in the normal circadian day reinforces one's circadian rhythm). Some individuals who are required to function during the normal circadian night are able to adjust to some degree; others are not and may develop a shift work sleep disorder.[7]

Types of Shift Work

Shift work may encompass several aspects of work scheduling. This may include working hours outside of what would be considered "normal" daytime hours such as between 7 AM and 6 PM,[8] overtime work (beyond a 40-hour workweek), or extended shifts (longer than 8 hours). Hours of work may be fixed or rotating, with modifications in schedules being predictable or unpredictable. Extended shifts may be voluntary or mandatory. Although some industries are governed by federal hours of service regulations (eg, aviation, highway, rail by the US Department of Transportation), and others may be guided by industry standards (eg, resident duty hours by the Accreditation Council of Graduate Medical Education), currently there are no duty hour standards issued by the Occupational Safety and Health Administration (OSHA).

According to a recent survey, 20% of wage and salary workers work a shift other than a regular daytime shift, with almost 15 million Americans working full-time on evening, night, or rotating shifts, or other employer-arranged irregular schedules.[9] Although many who work outside of what would be considered normal work hours do so because it may be the nature of the industry or the only position available, others choose to work these types of schedules for personal reasons (second jobs, childcare, education, better pay, etc). The National Sleep Foundation's 2010 Sleep in America poll found that one-fourth of those surveyed indicated that their work schedule did not permit them to obtain adequate sleep and one-third reported that they did not obtain sufficient sleep to function at their best.[10]

Occupational Risk Exposure of Shift Work

There is ample evidence that fatigue associated with extended hours, night shifts, and rotating shifts can have a negative impact on safety and performance. This is, in part, due to the shorter duration of sleep these individuals obtain, but it is also related to circadian misalignment. Duration of sleep is less than ideal among shift workers and worse for those on night shifts.[11] Twenty-four hours of sleep deprivation has been shown to impair neurobehavioral performance comparable to a 0.10% blood alcohol level.[12] Small amounts of sleep loss can affect the ability to sustain vigilance on some tasks. Only 2 hours less sleep per night than optimal over a week can lead to performance decrements equal to 24 hours of consecutive wakefulness.[13]

Several fatigue and alertness studies have demonstrated that incidents are more related to time of day than to time on task, with an increased risk of fatigue-related incidents in the early morning hours, coinciding with the circadian period of peak sleepiness. Similar to other impairing conditions such as hypoglycemia and the effects of medications, individuals are poor at assessing their own levels of alertness with subjective reports not correlating with objective measures. Not everyone who works extended hours or night shifts is equally impaired by sleep loss. In fact, significant individual differences in levels of alertness and performance have been observed.

One industry where the effect of fatigue on safety has long been recognized is transportation.[14–16] The National Highway Traffic Safety Administration estimates that at least 100,000 police-reported crashes annually are due to driver fatigue; these crashes cause approximately 1550 deaths, 71,000 injuries, and $12.5 billion in monetary losses. The National Transportation Safety Board (NTSB) has investigated numerous crashes in all transportation modes where fatigue has been found to be a causal or contributory factor.[17] Fatigue has been on the NTSB Most Wanted List every year since it was initiated in 1989.

In addition to the transportation industry, there has been a good amount of research into the effects of extended shifts and night shifts in health care workers. It has been found that nurses who work longer than 12.5-hour shifts have a greater risk of decreased vigilance on the job, of suffering an occupational injury, or of making a medical error.[18] Errors or injuries are also found to be increased in physicians in training when they work extended hours. The risk of an occupational sharps injury, of motor vehicle crash on the way home, or of making a serious medical error increases significantly because the hours on duty exceed 24 hours—compared with those working 16 hours—there are twice as many attentional failures and 36% more serious medical errors.[18]

An increased risk of motor vehicle crashes has also been reported in medical residents working extended shifts and consecutive night shifts.[19] Using the National Health Interview Survey, Lombardi et al[20] found that decrements in performance leading to increased injuries have been found

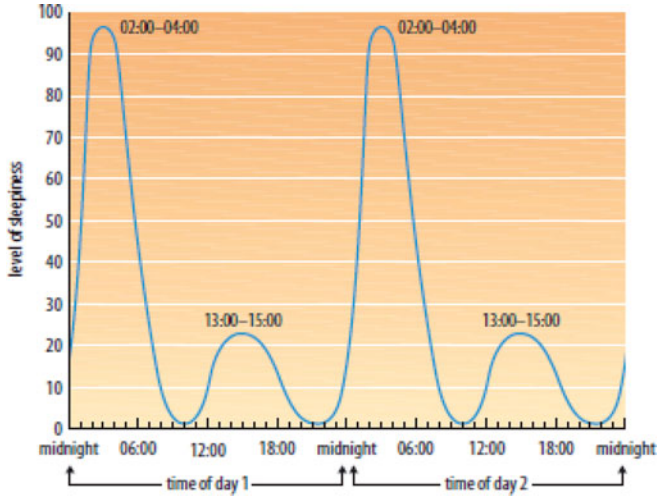

FIGURE 1. The circadian rhythm in sleepiness. Used courtesy of International Petroleum Industry Environmental Conservation Association/International Association of Oil and Gas Producers.[6]

TABLE 2. Estimated Annualized Injury Rates/Hours of Sleep*

	Estimated Annualized Injury Rates/100 Workers						
Hours of sleep	<5	5–5.9	6–6.9	7–7.9	8–8.9	9–9.9	<10
Injury rates	7.89	5.21	3.62	2.27	2.50	2.22	4.72

*Adapted from Lombardi et al.[20]

across multiple industries (Table 2). Even after controlling for industry, occupation, type of pay, sex, age, education, and body mass, an increased work-related injury risk remained, associated with reported decreasing number of hours of sleep and increased work hours.[20]

Others have also reported an increased risk of work-related injuries in those working extended hours.[21,22] The number of hours worked in the week prior to the shift when the incident occurred also seems to be related to the safety risk. In manufacturing workers, Vegso et al[23] found an 88% excess risk in those who worked more than 64 hours the week before compared with those who worked less than 40 hours (after controlling for within-subject variables).

Research increasingly demonstrates a positive association between short sleep duration and a variety of medical conditions[24] including diabetes,[25] hypertension,[26] cardiovascular disease,[27,28] adverse reproductive outcomes,[29] and obesity and its resultant medical issues.[30,31] A recent report from the International Agency for Research on Cancer also linked shift work and circadian disruption to an increased risk of cancer.[32]

Estimates vary, but in 1997, losses to employers from sleep deprivation were reported to approach $18 billion per year.[33] A more recent study estimates a loss of $1967 per employee per year in lost productivity due to sleep loss.[34] When fatigue coexists with other causes of lost productivity, the condition-specific productivity loss is increased threefold.[35] A loss of productivity has been found when work occurs at night, with the number of successive night shifts, the length of the shifts, and the duration of time off work between shifts emerging as factors that may affect the degree of effect.[36]

THE HISTORY AND LIMITATIONS OF DUTY-REST REGULATIONS

Key Points:

- "Hours-of-service" guidelines were an early attempt to address fatigue.
- Other factors (besides hours spent sleeping or at work) affect alertness.
- Fatigue Risk Management Systems address these other factors.

Work-related fatigue due to excessive working hours is not new. It has existed since man was first placed in an environment where the demand for food and shelter exceeded an easily available supply. However, before the invention of electric light, illumination for working was provided only by fires, candles, or gas lamps. These sources did not provide the intensity of light needed for factory work, large-scale activities, or fine craftwork. The advent of the electric light provided levels of illumination equal to or better than daylight. Once installed, work hours were not limited by daylight. Instead of only having to work long hours during the summer, when daylight is at its peak, employees could now be expected to work longer hours all year round. Factories and shops could be run 24 hours a day. In 1910, prior to widespread use of the electric light, the average person slept 9 hours per night. Today, the average person is reported to sleep from 7 to 7.5 hours per night.[37]

Even military maneuvers have been affected by the institution of artificial light. In the past, most military engagements ended as the light faded, such as noted in almost all of the major battles of the American Civil War. However, the use of night vision technology has now expanded the role of offensive engagements into a 24-hour activity.

More recently, the widespread use of electronic measures that can recall people any time of the day or night, and the expectation that a person respond to the requests of others in different time zones, essentially eliminates a "regular" work day and places many employees in a 24-hour work mode.

As a result of these changes, people live in a 24/7 society, not as a matter of choice but as a necessity of modern life. Police, firefighters, hospitals, power plants, and other vital services cannot close down at 5 PM. Similarly, continuous operations such as refineries and chemical plants take more than 24 hours to start up or shut down. Thus, there is no alternative to 24/7 operations for these facilities. To mitigate the health and safety consequences of this, regulations and laws have been passed to limit the time worked and/or to set minimum standards for time off. This approach has been common among economically developed countries outside of the United States, but has also been applied to some safety critical industries within the United States. For example:

- *Medical:* The Accreditation Council for Graduate Medical Education issues duty hour standards for medical residents.[38]
- *Highway transport:* The Federal Motor Carrier Safety Administration has regulations defining maximum hours per day and per week for drivers of passenger vehicles and trucks.[39]
- *Rail transport:* The Rail Safety Improvement Act of 2008 defines maximum consecutive hours and days worked as well as defining minimum periods of rest between shifts and between work sets.[40]

However, there is an increasing realization that hours-of-service guidelines alone may not achieve the objective of maximizing alertness (and thus fitness for duty) among individuals performing safety-sensitive work. Employee alertness depends not only on how many hours worked but also on a variety of other factors including:

- what one does at work;
- when one is at work (relative to the individual's circadian rhythm);
- whether the work environment promotes alertness or fatigue;
- whether there are mechanisms in place to detect excess fatigue;
- whether one obtains adequate sleep during time off or uses that time for other purposes;
- whether one has a sleep environment that promotes high-quality restorative sleep; and
- whether one has emotional, physical, or medical issues that interfere with high-quality restorative sleep.

Although several of these factors are under the control of an employer, others are not. Thus, it is critical to enlist the entire workforce as active partners in managing risk associated with fatigue. Increasingly, industry and regulators are moving away from pure hours-of-service standards toward comprehensive FRMSs designed to promote alertness, minimize fatigue, identify evidence of excess fatigue, and mitigate either the fatigue itself or its potential consequences.

EMERGENCE OF THE FRMS AS THE INTERNATIONAL STANDARD FOR MITIGATING FATIGUE RISK IN SHIFT WORK AND 24/7 OPERATIONS

Key Points:

- An FRMS is analogous to (or a subset of) a safety management system (SMS).
- An FRMS is science based, data driven, and subject to continuous improvement; in short, it is a system to manage risk associated with fatigue.
- Fatigue risk management systems are designed to improve outcomes and are more flexible than duty-rest and hours-of-service regulations.

- All stakeholders share responsibility for complying with and improving an FRMS.

What is an FRMS?

Historically, safety management has been a largely reactive process. Incidents have been investigated and "learnings" communicated together with appropriate controls to prevent recurrence. However, in recent years, safety management has moved increasingly from a technical to a business function to allow safety, productivity, and cost to be effectively balanced.[41] The establishment of an SMS acknowledges that decisions made at many levels and in many parts of an organization can affect operational safety.[42,43] An acceptable level of safety is, therefore, the result of successful management techniques.

One of the principal components of an SMS is safety risk management, an activity familiar to OEM practitioners. In this process, an organization identifies the hazards to which it is exposed, assesses the risks associated with those hazards, and determines appropriate ways to eliminate the hazard or control the risk. Other elements of an SMS include establishment of a safety management policy, reporting processes, incident investigation, training and education, and audit; these elements are familiar to traditional safety management. However, when incorporated into an SMS, each element is linked into a formal structure involving people and resources aimed at achieving safety.[44] It is, therefore, a natural development to extend the SMS structure into the area of fatigue with the development of an FRMS. As fatigue became increasingly recognized as an operational risk, fatigue risk management itself became recognized and may now be defined as "explicit and comprehensive processes for measuring, mitigating, and managing" the actual fatigue risk to which a company is exposed.[45] However, it is most effective when integrated into or supported by an SMS, thereby forming an FRMS.[46]

An FRMS may be defined as follows:

> A scientifically based, data-driven addition or alternative to prescriptive hours of work limitations which manages employee fatigue in a flexible manner appropriate to the level of risk exposure and the nature of the operation.[47,48]

The Key Features of an FRMS

A number of authors have outlined the key characteristics of an FRMS, but the following concepts as defined by Moore-Ede[49] are generally considered essential to the success of FRMS implementations:

1. Science based: supported by established peer-reviewed science.
2. Data driven: decisions based on collection and objective analysis of data.
3. Cooperative: designed together by all stakeholders.
4. Fully implemented: system-wide use of tools, systems, policies, procedures.
5. Integrated: built into the corporate safety and health management systems.
6. Continuously improved: progressively reduces risk using feedback, evaluation, and modification.
7. Budgeted: justified by an accurate return-on-investment business case.
8. Owned: responsibility accepted by senior corporate leadership.

These characteristics can be translated into the core components of an FRMS. Although there is still some discussion, the following six elements of an SMS are considered to be essential[45,48,50,51]:

1. Safety management policy
2. Risk management
3. Reporting
4. Incident investigation
5. Training and education
6. Internal and external auditing[44,52,53]

An FRMS may include:

1. fatigue management policy;
2. fatigue risk management, including collecting information on fatigue as a hazard, analyzing its risk, and instigating controls to mitigate that risk;
3. fatigue reporting system for employees;
4. fatigue incident investigation;
5. fatigue management training and education for employees, management (and families);
6. sleep disorder management; and
7. a process for the internal and external auditing of the FRMS that delivers corrective actions through a continuous improvement process.

All but the sixth element are direct analogues of those found in an SMS. Sleep disorder management is unique to an FRMS.

An FRMS requires a senior manager to be ultimately accountable for managing fatigue risk. However, all key stakeholders need to be actively engaged. Thus, a positive organizational culture where employees and management trust one another and where information about fatigue is openly reported is important to the successful implementation of an FRMS. As with the management of all risks, however, there is not a "one-size-fits-all" solution and the FRMS must be developed in response to the needs of the industry, the regulatory environment, and the organization in which it applies.

New FRMS Regulations in Aviation, Railroads, and Other Transportation Modes

The road transport and aviation regulatory authorities in Australia and New Zealand were the first to trial the FRMS to manage fatigue. Although many of the initiatives are still at the proposal stage, the road transport and aviation regulators in Australia and New Zealand have begun to move away from prescriptive hours of work (HoW) limitations toward FRMS. Indeed, the heavy vehicle driver fatigue regulations developed by the National Transport Commission and introduced in September 2008 are an example of outcome-based legislation. This is a fundamental change in the management of fatigue. Rather than complying with prescriptive rules, companies are required to focus on outcome, in other words, the management of fatigue.

The new regulations differ from traditional approaches, as follows:

1. All operators have a duty to manage their employees' fatigue consistent with occupational health and safety legislation.
2. A chain of responsibility is established. Legislation determines that the responsibility to manage fatigue is not solely that of the driver and the operating company. Indeed, a number of parties in the supply chain have a legal responsibility for preventing driver fatigue and influencing fatigue risk. Responsible parties include the prime contractor, scheduler, consignor, consignee, and loading manager.[54]
3. Organizations can follow standard HoW or, if they demonstrate they are managing fatigue in a sophisticated manner, they can work according to more flexible HoW.[55]

The National Transport Commission has also adopted an FRMS approach to rail safety[56] providing detailed recommendations on the individual elements of the program. Importantly, they also provide information on the features of work patterns and the relationship between fatigue and unsafe acts to assist the operator in recognizing the complex relationship between fatigue and operational safety. Elsewhere, the principle of establishing an FRMS has received the most attention in Europe. At the start of 2009, the European Aviation Safety Authority released a Notice of Proposed Amendment requiring all commercial air operators to have an FRMS in place by mid-2012.[57] According to the Notice of Proposed Amendment, operators can use an FRMS as a basis for applying for derogation from existing flight time limitations. To obtain derogation, an operator will need to present a safety case, successfully demonstrating that an equivalent level of safety can be maintained while working outside of the existing limits.

The US NTSB has long considered fatigue as a major factor in transportation accidents. Over the years, recommendations have been made to all transportation modes to address fatigue, including that caused by medical conditions such as obstructive sleep apnea (OSA). In 2008, recognizing the role of formalized fatigue management, NTSB recommended that the US Federal Aviation Administration develop guidance for operators to establish scientifically based FRMSs and to design a methodology to establish the effectiveness of these systems.[58] The Airline Safety and Federal Aviation Administration Extension Act of 2010 required airlines to develop a fatigue risk management plan by October 31, 2010.

The Spread of FRMS Through Other 24/7 Activities

Although the concept of an integrated FRMS is relatively new and has largely been limited to the transportation industries, there are some examples of FRMS, fatigue countermeasures programs, and alertness management programs in place in other industries and activities.

Mining

The Tasmanian Minerals Council in Australia published its *Fatigue Risk Management Guide* in 2004,[59] and the New South Wales Mines Safety Advisory Council established a group in 2008 to develop a fatigue risk management standard for the New South Wales mining industry which was published in 2009.[60]

Health

Starting in the late 1990s, the Australian Medical Association's Safe Working Hours Project was developed and ratified in 2002.[61] To assist in a more comprehensive approach, the Australian Medical Association have provided guidance on performing a risk assessment, recognizing that the hazards associated with shift work and extended hours are complex.[62] Their code of practice outlines both risk assessment and risk controls including a series of strategies that comprise many of the elements of an FRMS including the design principles for schedules.

Pipeline

The US Pipeline and Hazardous Materials Safety Administration recently published a Notice of Proposed Rulemaking for control room management and human factors.[63] This document includes a specific section on fatigue mitigation including a number of the elements of an FRMS.

The New American National Standards Institute Standard for FRMS in the Petrochemical and Refining Industries

The US Chemical Safety and Hazard Investigation Board's report into the explosion at BP's Texas City refinery in 2005,[64] recommended that the American Petroleum Institute (API) work together with the United Steelworkers International Union to develop a consensus American National Standards Institute (ANSI) standard. The document should provide fatigue prevention guidelines for the refining and petrochemical industries that, at a minimum, limit hours and days of work and address shift work.

Although the United Steelworkers International Union withdrew from discussions, in accordance with the terms of the API standardization procedures,[65] the *ANSI/API Recommended Practice RP755 Fatigue Risk Management Systems for Personnel in the Refining and Petrochemical Industries*[66] was published in April 2010. The standard employs a comprehensive and systematic approach and acknowledges that a combination of FRMS components and HoW limitations are critical. RP755 was specifically developed for US facilities operating under OSHA's Process Safety Management Standard, 29 CFR 1910.119.[67] Companies may also voluntarily choose to take advantage of RP755 to design and implement FRMS across their other operations, including upstream and international operations.

Integration of FRMS With Other Safety and Health Management Systems

An FRMS is an SMS, or part of an SMS, which is focused on managing fatigue risk. Within an FRMS, the management of fatigue is data driven and flexible commensurate with the level of risk and the nature of the operation. In addition, an FRMS considers multiple sources of fatigue and provides integrated, multiple defenses against risk. To be effective, an FRMS requires clear lines of accountability, a just culture, and the integration of fatigue risk management into a company's everyday business.

BUILDING SUPPORT FOR AN FRMS

Key Points:

- The organization and employee share responsibility for preventing fatigue.
- The organization is responsible for systematic support of alertness.
- Given adequate time away from work, employees are responsible for making arrangements to get enough sleep.

Organization and Policies

An FRMS builds on corporate policies that establish the following:

- An organizational structure.
- Practices and procedures.
- Reporting and analysis.
- Training to implement the system.

The first requirement is an organizational structure to implement the FRMS and procedures. An FRMS is not simply a set of rules and static information about fatigue; it is a living process with an organizational proponent and regular activities. The size and composition of the FRMS organization will depend on the size and complexity of the company. For relatively small entities, the organization may be a single person within the safety department with these assigned responsibilities. For larger companies, the organization may consist of a fatigue management steering committee with representatives of the various stakeholder groups: personnel, work scheduling, manpower, safety, union or employee representatives, training, and any other group within the company that makes decisions that might impact work scheduling and fatigue, such as maintenance and emergency operations and outage management.

Roles and Responsibilities

In general, fatigue risk management is a shared responsibility between the organization and the employee, reflecting the principles of a "just culture."[68] The organization must arrange schedules of work that provide sufficient opportunities for rest, training to support fatigue management, and procedures for monitoring and managing fatigue within the organization. The employee has the responsibility to use available time to be rested and fit for duty, to attend training and implement recommendations, and to report cases of fatigue so that they can be better avoided in the future. Thus, employee groups should participate, at least at the local level, in developing the FRMS implementation plans. Ensuring that employees understand and embrace their responsibilities to report for duty well rested is just as important as arranging schedules that provide sufficient rest opportunities.

Operator/Manager

This role includes senior management, local or middle management, first-line supervisors and support organizations such as schedulers, human resources, and health care and safety professionals. Senior management should demonstrate consistent commitment to fatigue risk management as an important component of the organization's overall safety and health management system. This should be demonstrated through the ongoing commitment of adequate resources and regular stewardship of progress made in the development and implementation of an FRMS. This consistent commitment by senior management will help ensure the rest of the organization's ongoing focus on the FRMS.

Senior management should then assemble a team to develop a scientifically based FRMS that includes policies, training, data-acquisition processes, analysis methods, and management procedures to implement, audit, and guide the FRMS process. The leadership of this team should rest with line management; however, individuals with a variety of backgrounds and experiences should participate. Especially when internal resources are limited, consideration should be given to retaining third party experts in fatigue management as members of, or consultants, to this team.

There is a danger that the fatigue management steering committee will adopt a reactive approach to fatigue management, taking constructive action only in response to reports of fatigue or fatigue-related adverse events. The more effective approach is to minimize fatigue by using available tools to forecast potential fatigue well in advance of actual operations, and taking corrective action to proactively eliminate potentially fatiguing schedules or conditions prior to their occurrence. An indicator of a highly effective FRMS is the frequency of such proactive corrective actions.

Employees Play a Critically Important Role in a Successful FRMS

The only remedy for sleep deprivation is sleep, and it is the employee's responsibility to use sleep opportunities to obtain rest, sleep, and meals. Each person has a unique requirement for sleep. Only the individual can decide how much sleep is adequate to maintain alertness and performance. As a general guide, the average person is thought to require about 8 hours of sleep per day, although individual differences in sleep need exist, ranging from 7 to 9 hours. In general, responsibility rests with the employees to get as much sleep as needed and to take additional sleep when they feel fatigued or unfit for duty.

Receiving adequate sleep requires planning with future duty times in mind. For example, if duty will require an early morning awakening, then the employee should plan to go to bed early the night before so as to be fully rested for the next duty. If the next duty commences in the evening, the employee is responsible for taking an afternoon or evening nap so that he or she does not start work with 8 or more hours of continuous wakefulness before the start of duty. If circumstances preclude sufficient sleep to be alert and rested and to perform duty, whether the result of the schedule, illness, life events, or personal actions, it is the employee's responsibility to report their state of fatigue to the manager. The employee should not accept the responsibilities of duty when fatigued or feeling unfit to safely perform assigned duties.

DESIGNING AN FRMS: THE FIVE LEVELS OF DEFENSE

Introduction to Fatigue Risk Management: Hazards and Loss Prevention: Reason's Concept of Swiss Cheese Slices

Key Points:

- The system approach to preventing human error focuses on incorporating redundant safeguards and barriers; an error within such a system results from not one but several simultaneous failures.
- An FRMS includes at least four levels of barriers to prevent fatigue-related incidents.
- Preventing fatigue-related incidents involves human concerns (managing sleep) and system issues (staffing levels, appropriate amount of light in the environment, etc).

In 2000, James Reason[69] put forward two possible approaches to the problem of human error: (1) the person approach and (2) the system approach. The person approach concentrates on the errors of the individual—forgetfulness, inattention, carelessness, negligence, or even recklessness. On the contrary, the system approach concentrates on the premise that humans are fallible and errors are to be expected. Errors, therefore, are consequences rather than causes and largely due to systemic failures. Control, therefore, focuses on changing the conditions under which individuals work rather than trying to change the individual. Core to this is the concept of a "system defense" of barriers and safeguards. Under this model, an incident investigation focuses not on who made a mistake but how and why the defenses failed.[69]

High-technology systems provide a number of layers of defense within the operation. Some are engineered (alarms, automatic shutdowns, etc), some rely on people (control room operators) and others on procedures and administrative controls.[69] Ideally each layer would be complete and intact. However, in reality, there are still weaknesses and opportunities for failure. In other words, each layer is like a Swiss cheese slice with its many holes. The nature of the controls, though, means that the holes on the slices are continually opening, closing, and moving. Holes in one slice alone will not lead to an incident but, on occasions, the holes in multiple slices will line up to allow a path through the system and a loss to occur.

The holes in the defenses arise for two reasons: (1) active failures and (2) latent conditions.[69] Active failures are the unsafe acts of individuals. They may, for instance, be slips, lapses, mistakes, or deviations from procedures. Their impact on the integrity of the system is usually short lived. Latent conditions on the contrary arise from decisions made by designers, procedure writers, and senior management. They may lead to conditions (eg, understaffing, fatigue, etc) that in turn may lead to long-lasting weaknesses in the defenses (eg, unworkable procedures). Being latent, however, these conditions may go unnoticed for many years. Unlike active failures that are often difficult to foresee, latent failures can be identified and rectified.

Key Defenses of an FRMS

Key Points:

- The five levels of defense against errors from fatigue include
  1. balance between workload and staffing;
  2. shift scheduling;
  3. employee fatigue training and sleep disorder management;
  4. workplace environment design; and
  5. fatigue monitoring and alertness for duty.

If Reason's concept is extended into the area of fatigue management, the fatigue-related accident or incident is the final step in a succession of causal links, all of which have failed to prevent the accident or incident. Dawson and McCulloch[70] suggest that there are four levels of prior event common to any fatigue-related accident or incident. In other words, such an accident or event is the end point of a causal chain of events (Fig. 2).[70]

Each level, therefore, provides an opportunity to identify the presence (or absence) of appropriate control mechanisms in the FRMS. Moore-Ede[49] further extended this concept while emphasizing the importance of building and managing an FRMS as a fully integrated system that provides a series of "defenses in depth" against the risk of fatigue. In Moore-Ede's view, there are five such defenses that need to be managed by the FRMS, which are as follows:

1. Workload–staffing balance.
2. Shift scheduling.
3. Employee fatigue training and sleep disorder management.
4. Workplace environment design.
5. Fatigue monitoring and alertness for duty.

The first three of these impact sleep management, and the last two affect alertness management, a subtly but significantly different goal (see Fig. 3). Each will be explored in more detail in the following sections.

The Supporting Framework to the FRMS

For an FRMS to be effective, each defense must in turn be integrated into the overall framework of the program. In Dawson and McCulloch's model[70] (Fig. 2), the level 1 control requires the employee to be

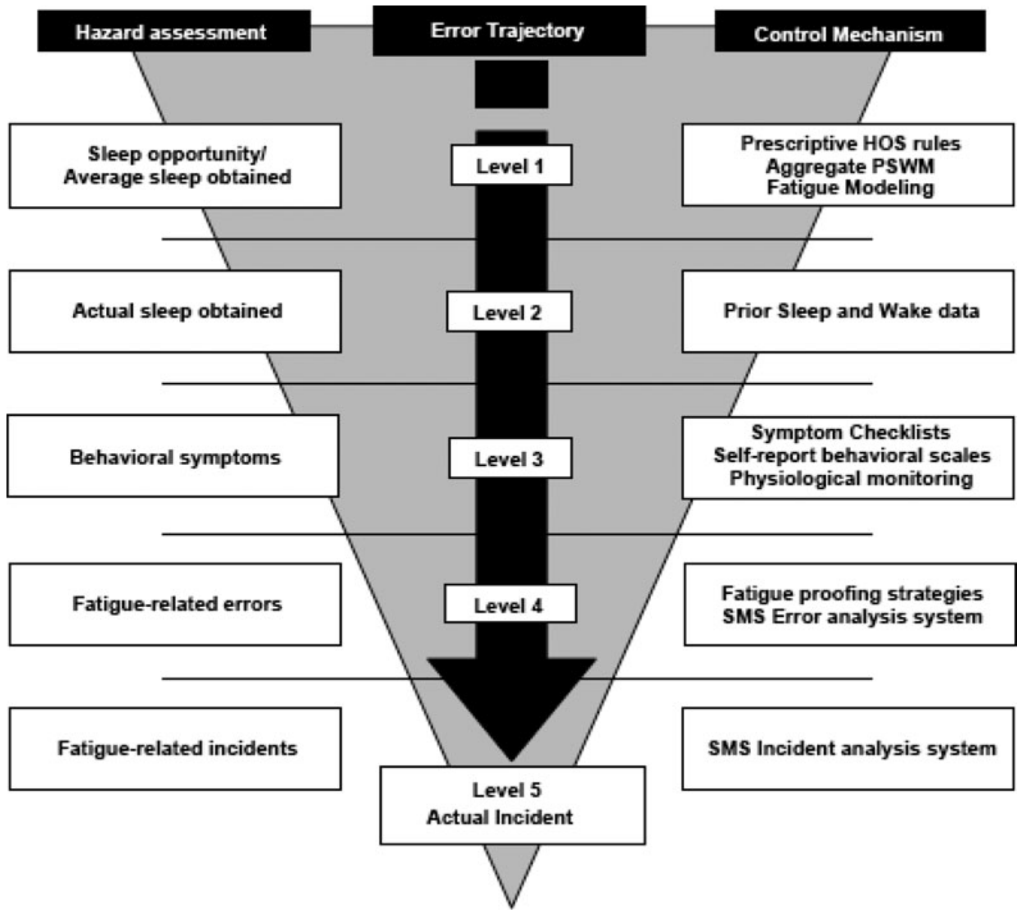

FIGURE 2. Fatigue risk trajectory. PSWM indicates prior sleep–wake monitoring; HOS, hours of service; SMS, safety management system. Reprinted with permission from Dawson and McCulloch.[70] Copyright 2005, Elsevier.

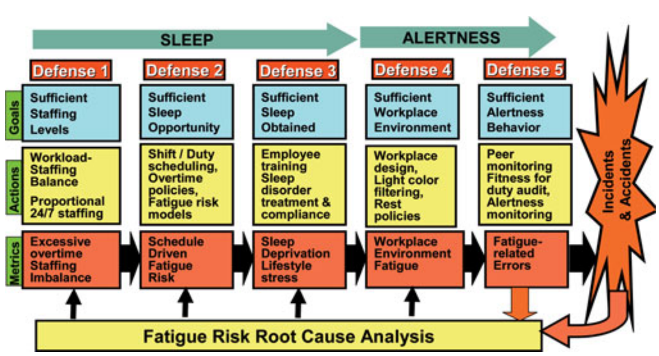

FIGURE 3. The five key defenses of a fatigue risk management system. Reprinted with permission from Moore-Ede.[49] Copyright 2009, CIRCADIAN®.

allowed an adequate opportunity for sleep. At level 2, the control needs to ensure that the employee actually obtains adequate sleep. At level 3, it is necessary to ensure that employees who obtained adequate sleep are not experiencing fatigue-related behaviors because of, for instance, sleep disorders. At level 4, we need controls to ensure that the fatigue-related errors do not lead to fatigue-related incidents. Finally at level 5, in the event of a fatigue-related incident, the FRMS needs to provide an incident investigation process to identify how and why the control mechanisms failed. This aligns very closely with Moore-Ede's model[49] (Fig. 3) with the workplace environment (Defense 4) embracing the system approach and, together with Defense 5, ensuring that the fatigue-related errors do not lead to fatigue-related incidents.

Defense 1: Address Staffing Issues in Fatigue Risk Management

Key Points:

- Imbalance between workload and staffing levels can worsen problems with shift work.
- Scheduled and unscheduled employee absences can worsen problems with shift work.
- Changes in workload (increased demand, merging of facilities, etc) can worsen problems with shift work.

One of the most important (but frequently overlooked) root causes of employee fatigue is an imbalance between workload and staffing levels. Extensive academic research and employer attention has been paid to the relative merits and risks of shift scheduling alternatives such as 12-hour shifts versus 8-hour shifts, fixed shifts versus rotating shifts, clockwise rotating versus counterclockwise rotating shifts, fast rotating versus slow rotating schedules, etc, without

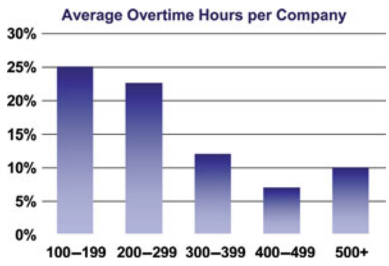

FIGURE 4. Average employee hours of overtime per year in North American shift work operations by number of shift workers. Reprinted from Moore-Ede and Kerin[71] by permission of CIRCADIAN®.

recognizing the underlying impact of staffing levels in the outcome metrics that are used.

For example staffing levels, *not* shift schedules, play the largest role in determining the following:

- average amount of overtime per employee;
- average time off between shifts;
- average time off between consecutive blocks of shifts;
- average length of shifts;
- average work hours per week;
- average number of consecutive days worked;
- discrepancy between the published shift schedule and the actual shift schedule worked.

This is because, in most 24/7 operations, the number of positions to fill on each shift is fixed. If the staffing level is lower than optimal, then the employees in that operation have to work additional hours or extra shifts to keep the positions filled. These hours may be added by:

- holding employees over for additional hours at the end of their shift (increasing average shift length and reducing off-duty rest hours after the shift);
- bringing in employees early for additional hours at the beginning of their shift (increasing average shift length and reducing off-duty rest hours before the shift);
- bringing employees into work on their days off for additional shifts (increasing the number of consecutive workdays and/or reducing the number of consecutive days off);
- having employees work double or even triple shifts (increasing average shift length and reducing off-duty rest hours after the shift); and
- short notice call-in to cover vacant positions (potential to miss a planned sleep period and start shift unrested).

As a result, the amount of overtime worked by employees is increased, and the additional hours and days worked make the published shift schedule a work of fiction. (Figure 4 shows prevalence of average overtime levels from a survey of 623 North American shift work operations.[71])

These average levels of overtime are not, however, evenly distributed among employees. In some cases, 80% of the overtime is worked by 20% of employees, with the result that the overtime levels in these individuals is much higher than the facility average.

Causes of Understaffing

The mathematics of staffing a 24/7 operation can look deceptively simple, if you overlook the operational realities of running the business. To start with the simplest example of a 24/7 operation running at a steady level with an equal number of positions to fill on every shift, the usual approach is to take the 168 hours per week and distribute the work to 4 crews each working 42 hours a week on average. This creates a weekly built in overtime of 2 hours every week based on the standard 40-hour workweek. This may seem straightforward enough but it overlooks that during any given week employees may not be available to fill their scheduled positions because of:

- vacation days,
- sickness absenteeism,
- non-sickness absenteeism,
- training,
- other special work assignments,
- jury duty, and
- turnover (delays in filling position with adequately trained employee).

Many 24/7 operations do not realistically estimate or measure the full impact of these factors and hence design a shift operation with fewer staff than optimal, increasing the overtime level worked and impacting the time on duty and off duty. Many companies do not analyze their historical work and human resources data, so they are unable to make even simple forecasts about sickness and absenteeism, and they are unable to accurately define seasonal, weekly, and daily fluctuation in demand.

The root cause of this staffing workload imbalance is not just careless arithmetic. Over the last 20 years, there has been a major effort to reengineer business processes, taking advantage of automation to improve productivity (loosely defined as product output or revenue generated per employee). As a result, the productivity of businesses has dramatically increased whereas the headcount has been reduced.[72] Operating managers may seek to be responsive to corporate mandates by reducing the staffing toward the minimum required to cover base hours, without fully understanding the risks of employee fatigue that are involved.

The actual cost savings are not what they seem. It is true that by cutting staffing levels and relying on overtime to fill open shifts, the total paid out in benefits and training costs is reduced, usually estimated to be around 50% of base salary. However, filling the open shifts by using overtime incurs the cost of paying time and a half or even double time on holidays, so there may be little if any actual cost savings.

Furthermore, according to some studies, the amount of productive work performed per week per employee caps out at as little as about 50 hours. Consequently, more than 10 hours of overtime per week may not provide much additional productive work. On top of that, as discussed more fully later, excessive levels of overtime are associated with increased fatigue and greater risk of costly errors, injuries, and incidents, further making understaffing a losing proposition.

Another common scenario where staffing–workload imbalances and overtime can increase significantly is when production has to be increased because of greater market demand or increased sales targets. Alternatively, businesses may want to increase their utilization of capital equipment by as much as 40% by closing some older operations and converting the remaining sites to seamless 24/7 operations. Operations that had been running 24-hours a day for 5 days a week now extend their workweek to 6 or 7 days. In such situations, especially where there is uncertainty about how long the increased business demand will last, managers may be reluctant to hire more employees. Instead, they try to cover the new shifts with overtime. As a result, employees now may be working 6 or 7 days a week with occasional days off, and experience burnout from fatigue and stress.

In some industries the entire facility is periodically shut down for repair or maintenance. Such outages are very costly because production stops, and there is an enormous incentive to get the plant back on line as soon as possible. Outside contractors may be called in, but often the employees are asked to work everyday during the extended shutdown period, again increasing their overtime and fatigue risk. For example, the US Chemical Safety Board in its investigation of the 2005 BP Texas City oil refinery explosion that killed 15 and injured 170 workers found that the control room operators on duty at the time were working their 30th consecutive 12-hour night shift. This eventually led to the creation by the oil and petrochemical industry of the API-ANSI standard RP755, which requires US petrochemical facilities to implement a comprehensive FRMS that includes addressing staffing–workload imbalances.

Other Causes of Understaffing

So far we have looked at the simplest staffing model of 24/7 operations where the workload is the same every hour of the 168-hour week, and the same everyday of the year.

But, many shift work operations are not like this. Workload often fluctuates for a variety of reasons by:

- times of day,
- days of week,
- seasons,
- economic cycles, and
- randomly (customer demand, weather, unpredictable events).

If such operations are staffed at the same level on all shifts, management may try to pick an average staffing level required. This can result in a constant oscillation between being overstaffed (with unproductive increased cost) and being understaffed (with increased employee stress and fatigue). An example of this is a major city police force that until recently was staffed with the same number of patrol car officers for every shift of the week, this despite the fact that the number of emergency calls on Friday and Saturday nights was many times higher than, for example, on Tuesday afternoons. In less extreme examples, 24/7 operations may try to predict the necessary staffing level hour by hour, day by day, or month by month, but invariably estimate incorrectly some of the time.

If the business is highly unpredictable, staffing levels are often minimized by using a first-in, first-out board where each employee finishing a duty period enters the bottom of the board, and the employee at the top of the board is the next to be called to duty. As duty assignments are made, each employee's name progresses up the board until they are called for duty, often at short notice (eg, 2 hours or less), when their name reaches the top of the board. The consequence is that duty-rest schedules are irregular and unpredictable, which makes sleep planning very difficult.

Such first-in, first-out boards are used by freight railroads to call locomotive engineers and conductors to work, especially for reserve crews who work on extra boards, and by marine pilots called to pilot ships in or out of harbor. The number of employees on the first-in, first-out board determines the risk of fatigue, because the fewer the employees, the more frequently they are called and the shorter the average rest period between duty periods. (Figure 5 shows that by using fatigue risk models, the minimum staffing level can be determined. When the number of employees is reduced to the point where it restricts adequate rest, the fatigue risk increases.[73])

Consequences of Understaffing

Understaffing affects both acute and chronic fatigue levels, by increasing the probability of shortened sleep and extended time on duty as well as increased overtime and unpredictability of the work-rest schedule. Up to a point, overtime is welcomed by employees as a way to increase the paycheck. Some employees will volunteer for more overtime than others, which buffers those who do not want the extra hours. An 80:20 rule is often seen, where 20% of employees are volunteering for 80% of the available overtime. Note, that volunteering for overtime has to be managed. Otherwise, the high overtime employees risk becoming dependant on the substantially increased paychecks over base pay, because they may get committed to financing obligations (such as larger or second homes, boats, etc), beyond what they can afford on their base pay. Such employees can get trapped in a position where they need the overtime, regardless of changes in other circumstances, be they medical, psychological, social, or simply age. The risk of fatigue in these employees can be significant, because getting adequate sleep may become a secondary priority.

Even more insidious is the vicious cycle between overtime, absenteeism, and turnover that is created by understaffing a 24/7 operation. (Figure 6 shows that increased overtime is associated with increased absenteeism based on a survey of approximately 400 industrial 24/7 operations.[74])

When imbalances increase between staffing and workload, overtime often has to become mandatory to fill the positions. In such situations, absenteeism rates increase because employees find they become over-fatigued and over-stressed. Each open position created by an absent employee has to be filled, which increases the amount of required overtime even further, and increases the pressure on the other employees to add more overtime hours. If continued over a period of time, employees may decide they cannot cope with the stress and fatigue and quit their jobs, increasing the turnover rate. This in turn increases the number of open positions and overtime levels required while replacement employees are recruited, hired, and trained, thus driving the vicious cycle faster and faster.

Addressing Workload–Staffing Imbalances

The workload–staffing imbalance is one of the first issues that must be addressed in designing and implementing an FRMS for two important reasons:

1. The causal chain of employee fatigue risk starts with workload–staffing imbalances as shift schedules and duty-rest rosters cannot be designed unless one knows the staffing levels; education and training, as well as fatigue management policies, should be specific to the schedules that are designed.
2. The largest perceived cost in implementing a corporate FRMS is often thought to be in the hiring and training of new employees if workload and staffing are significantly out of balance. However, unless training and hiring costs or pension obligations are very high, this is actually a false assumption as discussed earlier. This requires senior management education on true staffing costs and fatigue risks.

Determining the necessary staffing levels may seem easiest if hours of service laws, regulations, ANSI standards, or union agreements exist which set the outer boundaries on HoW and hours of rest. However, operating up against the outer boundaries of

FIGURE 5. Effect of reducing the staffing level (number of qualified marine pilots) on fatigue risk (% time significantly sleepy) at three different levels of workload (ships per month to pilot) in 3 separate months. Reprinted from Moore-Ede et al,[73] by permission of CIRCADIAN®.

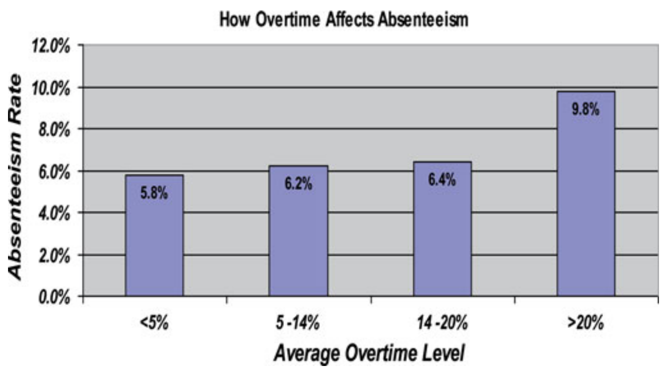

FIGURE 6. Dependence of the absenteeism rate on the average level of overtime. Reprinted from Aguirre and Moore-Ede[74] by permission of CIRCADIAN®.

these rules may cause excessive employee fatigue because it is hard to write simple rules to cover all combinations of possibilities, particularly with regard to circadian time of day risks. Indeed, the API-ANSI RP755 standard for the petrochemical industry FRMS specifically cautions against consistently operating at its outer hours of service boundaries.

Before hiring additional employees, it is worth carefully analyzing the workload–staffing imbalances and options for addressing them. These include:

- reexamining and reengineering processes to reduce the number of employee positions or the types of jobs that are needed to be filled per each shift;
- cross-training employees to fill positions to increase the available staff; and
- examining the fluctuations in workload to determine predictable patterns and building a proportional staffing system that better matches fluctuations in workload.

Once all these options have been explored, a scheduling factor analysis is needed to ensure that proper accounting of vacations, absenteeism, and other causes of open positions has been done. Once staffing levels are properly adjusted then optimal shift schedule can then be designed.

Defense 2: Shift and Duty Scheduling

Key Points:

- Circadian misalignment occurs when the sun "tells" the employee to be awake during the day and the employee's work schedule requires being awake at night.
- A combination of three strategies can reduce the risk of fatigue during shift work.
- Biomathematical models can be used to estimate the effects of duty scheduling on the level of worker fatigue.

One potential source of fatigue is the work schedule itself. The work schedule defines the time in the day when sleep cannot occur, and, hence, the nonwork periods define the maximum sleep opportunities—the total time when sleep might occur to restore or sustain performance. The true sleep opportunity is some amount of time less than the nonwork time because we must deduct the time required to travel to and from work (commute time) and time to engage in necessary personal activities, such as eating and personal hygiene.

As previously noted, the average person requires 8 hours of sleep per day, so sleep opportunities must be longer than 8 hours per day to permit restorative sleep and prevent fatigue associated with sleep loss. Furthermore, opportunities to sleep at night are generally more restorative than equivalent opportunities to sleep during the day because human physiology is programmed to sleep during the dark hours of the day. Humans are diurnal animals.

Sleep difficulties are commonly associated with shift work because sleep disturbances and sleepiness are the most commonly reported complaints of shift workers.[75–77] A common belief is that, over time, shift workers adapt to their non-standard sleep and wake hours and that all of their initial problems associated with shift work subside. This is actually not usually true. Shift work is not just about sleep; it is a more complex issue.

Shift work, a term referring to non-standard schedule, is associated with the disruption of an individual's underlying physiology. Shift schedules require workers to override the internal biological clock that programs humans for daytime activity and nighttime sleep.[78] This produces "circadian misalignment," a condition in which the biological clock remains synchronized to the local time (because it is driven by exposure to the local pattern of sunlight) but the sleep–wake cycle is not synchronized with the local time. The result of circadian misalignment is a sleep period that occurs at an adverse circadian phase, when the body is programmed to be awake. This can cause sleep difficulties (eg, longer than normal times to fall asleep and early termination of sleep) that can lead to continuous partial sleep deprivation and chronic sleep loss.

The shift worker is further challenged by the fact that his or her sleep–wake cycle is constantly altered between work days and nonwork days because of conflicting time cues from the day–night cycle and a day-oriented society (eg, keeping the same day schedule as the family on nonwork days). So the shift worker that must work at night is subject to chronic sleep loss that adds to the inherent risk of working at night when a person's physiological rhythm is programmed to be asleep.

Hence, the shift worker on night shift can experience exaggerated drowsiness from the combined effects of the circadian nadir in alertness and potential sleep deprivation. The risk associated with this combination can increase with the frequency of night shifts because shift workers seldom obtain the same amount of sleep during the day because they would normally obtain when sleeping at night. Over multiple night shifts requiring sleep in the daytime, workers can accumulate an increasing sleep debt. Research indicates that incident risk increases with successive night shifts.[79]

There is no single remedy to this schedule-induced risk. The best way to protect against schedule-induced fatigue risk at night is to combine three strategies: (1) schedule design that permits frequent opportunities to obtain nighttime sleep to recover from sleep debt on the night shift; (2) training of workers to make maximum use of daytime sleep opportunities through optimal sleep hygiene; and (3) environmental and task engineering to maximize alertness on the job and protect against errors that occur so that they are detected and corrected before cascading to a serious incident.

Shift Rotation

Shifts can rotate clockwise (ie, morning–afternoon–night) or counterclockwise. There is no strong evidence that sleep or accident risk differs based on direction of rotation. Clockwise rotation has the advantage that there is typically about 16 hours between each shift, offering maximum sleep opportunities. Clockwise rotation also places the night shift immediately before a break so that recovery occurs on personal time. However, there are many variations on both counterclockwise and clockwise rotation, and the relative advantages of each for sustaining alertness are difficult to estimate without using a computer simulation of the underlying physiology.

Shift Handover

When on day shifts, individuals tend to go to sleep at a similar time, regardless of when they need to arise. Thus, an early shift handover, requiring those on the day shift to awaken early, may increase fatigue for those on the day shift. On the contrary, an early handover allows the night shift to go home and sleep while their circadian rhythms are still near the nadir, that is, when it is easier to fall asleep. The optimal shift handover time is a function of the lifestyles of the shift workers and should be chosen with their input, preferably after they have been trained regarding alertness strategies for shift work (see Defense 3A Employee Training, Education, and Defense 3B Sleep Disorder Management).

Shift Length

The longer the shift, the greater the amount of time since the last sleep period and the greater the effects of accumulated "away-from-sleep time" on task and workload effects. Research suggests that as shifts exceed 8 hours, there is an increasing risk of error.[79] That same study indicates, however, that breaks within the schedule to fight time-on-task fatigue can greatly mitigate the increased risk associated with shifts longer than 8 hours. Bear in mind that shorter shift lengths mean more shift handovers (another source of increased incidents).

Double Shifts and Extra Shifts

The nominal shift schedule is often not the actual work schedule. Absences require others to work double shifts or accept additional shifts. These changes in the work schedule further reduce opportunities to get sleep for those workers that take the extra or extended shifts. Sleep loss is cumulative and continues to degrade performance until a break permits recovery sleep. Because of the multiple ways changes from the nominal schedule can interfere with sleep, the true effects of shift work on performance is best estimated from the actual schedule, not from the planned schedule.

Biomathematical Modeling of Shift Schedules

Biomathematical fatigue models simulate the interplay of circadian variations in alertness and sleep tendency, patterns of sleep that maintain or restore performance capacity, and short-term sleep inertia following awakening. Examples are the Sleep, Activity, Fatigue, and Task Effectiveness model,[80] the Fatigue Avoidance Scheduling Tool,[80] the Fatigue Audit InterDyne,[81] and the Circadian Alertness Simulator.[82] Models differ in how these three factors are represented mathematically and the predictions may be in abstract units of fatigue, subjective units of alertness, or estimated units of performance speed. For example, the fundamental predictions of one commonly used model are in terms of changes in cognitive speed, expressed as percent of baseline performance when well rested. This measure corresponds to speed of response on a reaction time task.

Studies have shown that simple reaction time is highly correlated with performance on other cognitive tests.[83] However, cognitive fatigue is independent of physical fatigue. Thus, models of cognitive fatigue are good at estimating likelihood of error due to fatigue; they are not designed to predict the onset of physical exhaustion or muscular fatigue.

Whatever the units of the model, they can be used as tools for making comparative judgments about the cognitive fatigue risks associated with alternative schedules. It is assumed that the model predicts changes in the fundamental capacity to perform a variety of tasks that rely, more or less, on the cognitive skills of detection, discrimination, reaction time, mental processing, reasoning, and decision-making. However, specific operational tasks vary in their reliance on these skills, and deficits in cognitive capacity or alertness may not produce identical reductions in the capacity to perform all operational tasks.

Nevertheless, it is reasonable to assume that when comparing schedules, differences in task performance and risk of error would be correlated with predicted changes in the underlying cognitive capacity or alertness. For example, Fig. 7 illustrates that there is a systematic relationship between predicted performance speed and driving simulator accident data from subjects given varying amounts of daily sleep for a week.[84]

Prediction of operational task performance could be used to alter the timing of critical tasks so they coincide with periods of optimal performance, design improved work schedules, and/or introduce countermeasures in the workplace to prevent errors and accidents. Fatigue and performance models also offer physiology-based, flexible ways to optimize safety and performance beyond what prescriptive hours-of-service regulations can provide. Current uses of fatigue modeling include:

- prediction of risk of impairment in a given work–rest or wake–sleep schedule;
- guidance for the effective implementation of fatigue countermeasures;
- as a component of FRMSs;
- to inform, supplement, or substitute hours-of-service policies and regulations;
- as an aid in post hoc incident/accident investigation; or
- as an educational tool for understanding fatigue and its consequences, and for reinforcing the importance of good sleep hygiene.

The accuracy of any model will depend on the accuracy of the major inputs to the model. In operational settings, one of the key inputs is the pattern of sleep achieved under a work schedule. In laboratory studies, models of performance utilize precise brain-recorded measurements of sleep; these precise sleep measurements are not available in the workplace. However, a variety of techniques can be used to estimate sleep. These include recording sleep with an actigraph, using sleep diaries, and using an algorithmic sleep estimator.

Although even algorithmic sleep estimation can be sufficient to detect elevated accident risk,[85] the predictions will necessarily be imperfect given the errors in sleep estimation. However, such estimates are generally considered sufficient for comparing schedules with large groups of workers where errors cancel; they would be problematic for predicting the alertness of any given individual with an idiosyncratic sleep pattern. Other limitations of fatigue models are uncertainty about the initial state of the individual prior to the schedule under study, the precise timing of the circadian rhythm, and the sensitivity of any given individual to the effects of sleep restriction.

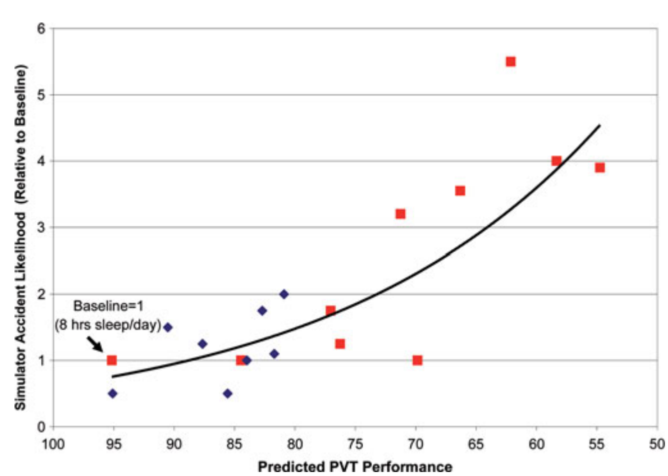

FIGURE 7. Limitations of fatigue models. From Balkin et al.[84]

Finally, fatigue models are designed to predict cognitive capacity either in terms of some objective measure of performance or in terms of subjective reports of alertness. Reductions in capacity will have varying impact on the ability to perform specific tasks or elevate the risk of making an error or, more rarely, causing an accident.[85] It is important to keep in mind the nominal predictive capacity of the model and to what extent this coincides with other aspects of performance and safety.

The typical fatigue model assumes that the magnitude of fatigue is independent of the nature of activities while awake. However, fatigue varies with the demands of the job: It increases with time on task,[86] with successive duty periods in shift work,[87] and with the duration of the shift. Conversely, fatigue diminishes with rest breaks and days off.[79,88]

Other modulators of fatigue, such as pharmacological countermeasures (eg, caffeine), are also not covered by typical fatigue models. As such, predictions of fatigue models must be interpreted as representing the general tendency of the population under normal conditions. How predictions in performance capacity relate to potential error and risk depends on the nature of the tasks and on the circumstances at hand.

Defense 3A: Employee Training and Education

Key Points:

- Responsibility for fatigue risk management is shared by management and the individual employee.
- Management is responsible for staffing, scheduling, and training.
- Employees are responsible for using the opportunity to sleep appropriately, for using fatigue assessment tools, and for obtaining medical care for sleep disorders.
- Science is advancing in this area—stay alert for new technologies to help manage fatigue.

As previously noted, fatigue risk management is a shared responsibility. Although many interventions to minimize fatigue and enhance alertness of the workforce are in the hands of management, some of the most important elements are under the individual employee's control. Employees have the primary responsibility to report to work well rested and fit for duty. However, it is incumbent upon management to provide the motivation, knowledge, and in some cases, the resources to allow them to do so.

It should be emphasized that information is not enough. In many cases, employees are being asked to make significant changes in their lifestyle such as taking the time to obtain enough sleep. Understanding why this matters to them, their family, and their coworkers is critically important to motivating these changes. That said, fatigue risk management training can positively impact both knowledge and behavior.[89] Thus, employees should be educated on the following principles concerning alertness management:

- Hazards of working while fatigued and the benefits of being well rested.
- Impact of chronic fatigue on personal relationships, mental/physical well-being, as well as general life satisfaction.
- Recognizing that although fatigue cannot be eliminated, it can be managed and minimized.
- Adequate quantity and quality of sleep is key to managing fatigue.
- Basics of sleep physiology, circadian rhythms, and what is getting adequate sleep.
- Sleep hygiene—how to obtain adequate quantity and quality of sleep.
- Sleep disorders—why they matter, how to tell if one may have one, and what to do about it.
- Importance of diet, exercise, stress management, and management of other health conditions that affect fatigue, as well as information about how to address these issues.
- How to recognize fatigue in oneself or one's coworkers.
- Alertness strategies to be used while at work such as appropriate use of caffeine, rest or exercise breaks, and social interactions.
- Advice on managing personal relationships for shift workers.

Although computer-based training or written materials may be effective in conveying the information, they may not be as motivating as instructor-led training. Thus, where possible, consideration should be given to providing instructors, at least for initial training. Ideally, the training is given in small to medium size groups composed of natural work teams. Conducting the training in natural work teams allows it to be tailored to a group's specific circumstances and needs. For instance, a group that works rotating shift work may have different needs than another that works primarily a day shift but may work a fair amount of overtime or be called out periodically in the middle of the night. In addition, many individuals are more likely to speak up among friends and colleagues than among others they do not know well. Ideally, the training should be interactive.

Training, to be effective, needs periodic reinforcement. This reinforcement may take the form of newsletters and bulletins, computer-based refresher training, and/or "tool-box safety meetings." Family and significant others can have an important role, either in helping or hindering implementation of the needed changes. Some companies invite family members to accompany employees to the training. Alternatively, handouts can be given at the training with encouragement to take them home and talk about them with family. As with employees, a single exposure to this material is not enough. Periodic reinforcement is important for sustained change. Supervisors generally work alongside their work group and thus encounter the same challenges as their employees and the same training as their staff. Being trained alongside others may also emphasize the importance of training.

However, supervisors have special responsibilities and as a result require some additional training. They need to understand how to implement the company's approach to shift scheduling, including any guidance for determining when and how deviations can be implemented. They should be trained in how to recognize fatigue and what can be done to mitigate or manage it (fatigue countermeasures) both in the short-term and when/if it seems to be chronic. The specific content of supervisor training will likely vary from company to company, based in part on the nature of the work and shift patterns, but also on the corporate culture. For instance, in some companies encouraging the employee to take a brief nap may be a viable option to address short-term fatigue, whereas in others, "sleeping on the job" is not acceptable.

Defense 3B: Sleep Disorder Management

Key Points:

- Primary and secondary sleep disorders are common in the US population.
- Screening for sleep disorders ranges from questionnaires to diagnostic sleep studies.
- Treatment modalities exist for the common sleep disorders.
- Workplace programs can be developed to manage sleep disorders from screening through assessment of treatment adherence.

The Prevalence of Sleep Disorders Among American Workers

Fatigue is a common symptom for many Americans and can be defined as "a feeling of weariness, tiredness, or lack of energy." Fatigue is diagnostically nonspecific and is associated with many health conditions including physical and psychological disorders. It is estimated that approximately 38% of the US workforce is fatigued, which is consistent with prevalence estimates from many community studies.

One of the causes of fatigue to be considered is a sleep disorder. Currently, approximately 85 different sleep disorders have been identified[90,91] with more than 40 million Americans suffering from a sleep disorder. The most prevalent disorders include sleep apnea, acute/chronic insomnia, restless leg syndrome, and narcolepsy. Others that may lead to excessive fatigue in the workplace include insufficient sleep syndrome and the circadian rhythm sleep disorders including shift work sleep disorder.

In the 2008 Sleep in America Poll,[92] a study conducted by the National Sleep Foundation, about 1 in 7 respondents (15%) said a doctor had told them they have a sleep disorder and about 1 in 10 had been diagnosed with sleep apnea (9%), with only 5% of the total sample being treated at the time of the poll. Furthermore, 4% had been told they have insomnia and/or restless leg syndrome (3%), but only 1% to 2% were receiving treatment. Obtaining sufficient sleep is a challenge for those with abnormal or prolonged work schedules. Seven percent identified themselves as shift worker (beginning work after 6 PM but before 6 AM). More than half of the respondents indicated that they were working 40 to 49 hours per week, with 30% working 50 to 59 hours, and 13% reporting working 60 or more hours per week.

In addition, the 2008 Sleep in America Poll found that those who have been told by a doctor that they have a sleep disorder are significantly more likely than those who do not have a sleep disorder to sleep fewer than 6 hours on workdays (25% of those with sleep apnea, 38% of those with restless leg syndrome, and 36% of those with fatigue compared with 14% of those without a sleep disorder) and to use a "sleep aid" at least a few nights a week. In this poll, 12% of those surveyed indicated their work schedule does not permit them to obtain sufficient sleep.

The Impact of Sleep Disorders on Fatigue, Alertness, and Safety

Fatigue impairs work ability; those with fatigue are significantly more likely to miss work and experience long-term absence than those experiencing functional alertness.[93] Each year sleep disorders cost employers $60 billion in lost productivity, industrial accidents, and medical expenses.[33,94] Fatigue is a primary symptom of some common health conditions (including chronic fatigue syndrome and depressive disorders) that negatively impact work ability. This is in addition to medical conditions discussed elsewhere in this review.[95] The total annual cost of lost labor force participation resulting from unemployment among those with chronic fatigue syndrome is estimated at $6.8 billion and the total annual cost of lost productive work time among those with depression in US workers is approximately $31 billion.[95]

The Health Risks of Untreated Sleep Disorders and the Benefits of Treatment

Sleep disorders affect the quality and quantity of a person's sleep.[96] The discomfort and fatigue that result from sleep disorders are significant and vary with each person. Treatment for sleep disorders depends on the condition.[97] In addition, good lifestyle habits, proper sleep hygiene practices, and the use of a sleep diary are helpful ways to alleviate some of the discomforts associated with sleep disorders.[98,99] Although there are treatment options available for fatigue and insomnia, such as medication and behavioral therapy, prevention strategies are also available. Before expensive medications and visits to the therapist, psychiatrist, or psychologist, individuals can try the prevention strategies on their own or with the help of a health coach.

Some tips to help overcome insomnia and fatigue include:

- waking up at the same time everyday if possible;
- avoiding alcohol, caffeine, and nicotine before bed;
- exercising (but not within 3 hours of going to bed);
- sleeping in a dark, quiet, and cool room; and
- keeping a sleep diary to record sleep patterns and problems.

Napping is also helpful, especially for shift workers, to help supplement sleep. However, napping may be contraindicated for those who suffer from insomnia or other sleep disorders because it may reinforce erratic sleeping patterns that already exist, so it is important to consult a physician. Through simple lifestyle change, an individual may be able to alleviate the severity of their fatigue/insomnia. Constant adherence to these changes is important because it allows the body to become accustomed to the new lifestyle and gradually helps to lessen symptoms.[100]

Implementing a Workplace Sleep Disorder Management Program

If an employer is going to implement a sleep disorder management program, it may contain only a screening component with follow-up by a personal physician or be a complete program to include the following components: screening, confirmation, treatment, and compliance (Fig. 8).

Screening

The first step in screening for sleep disorders is likely to be a questionnaire, possibly combined with a physical examination for risk factors (obesity, neck diameter, fullness of soft tissues in the oropharynx, etc). There are various devices based on actigraphy that are used by some as a screening step as an alternative to a questionnaire: a sleep diary to document sleep patterns for several weeks; the Epworth Sleepiness Scale to assess daytime sleepiness; the Berlin survey to assess risk of OSA, actigraphy to assess sleep–wake patterns over time, and/or a mental health examination may be a part of the process.[101] Because insomnia may be a symptom of depression, anxiety, or another mental health disorder, a mental status examination, mental health history, and basic mental evaluation are part of the initial assessment. The screening may be by a questionnaire or a device such as an actigraph optimized for this purpose.

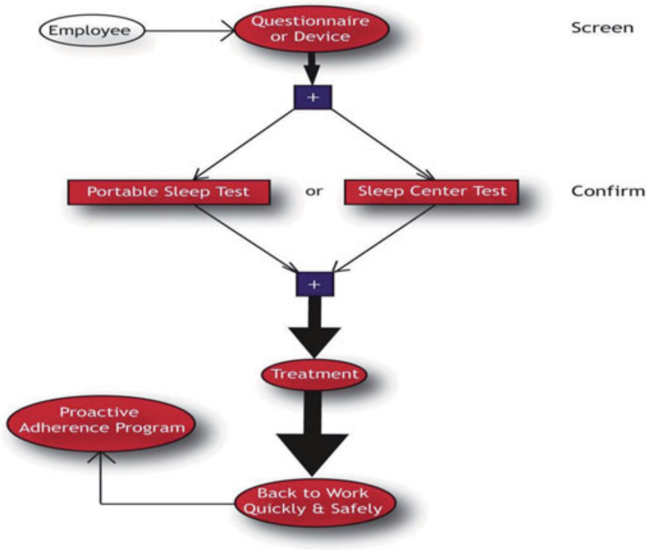

FIGURE 8. Schematic of a sleep disorder management program. With permission from University Services (unpublished data).

Diagnosis

To diagnose sleep disorders, a physical examination as well as a medical and sleep history by an appropriately experienced and credentialed physician will need to be conducted (sleep medicine is a recognized specialty of the American Board of Medical Specialties). During the examination, the physician will determine any medical or psychological illness that may be contributing to the sleep disorder. Possible causes a physician may be looking for may include chronic snoring and recent weight gain, which might suggest sleep apnea as the cause of insomnia and/or other signs.

Typically, a polysomnogram is the most common diagnostic sleep study conducted. An individual stays overnight, usually at a sleep center, where their sleep and wake cycles are monitored for 8 to 12 hours. Various sensors measure brain activity, eye movements, heart rate, blood pressure, breathing activity, and effort and oxygenation status.[102]

Some individuals may be given the option to undergo an at-home sleep test (variously referred to as home sleep testing, unattended sleep study, portable sleep testing, ambulatory sleep testing). The device is dispensed or shipped to the individual and worn during sleep; then returned to the sleep center. The results should be analyzed by a registered polysomnographic technician and a Board-certified sleep physician.

Benefits to ambulatory testing include the ability to test individuals regardless of their location, the ability to receive a diagnostic report quickly, and the ability of the devices to provide diagnostic testing at a cost lower than that of a sleep center. These devices can only diagnose sleep apnea and if the clinical suspicion is that another or a coexistent sleep disorder exists, the individual should be referred to a sleep center for a comprehensive study.

When there is a concern that the ambulatory testing could be subverted by not following wearing instructions or having another person actually be tested, the test could be monitored, but not in a complete sleep laboratory. This would decrease some of the cost savings. Other types of tools are being developed to ensure that the appropriate person is being tested and that the equipment is used as required to obtain appropriate results. The Federal Railroad Administration partially funded a study with a class I railroad and University Services to establish that a study could be performed successfully through joint cooperation between the employer and employees.[103]

Treatment

If through evaluation it is determined that the individual is not obtaining sufficient sleep or if their work schedule is affecting their sleep patterns then behavioral modification and attempts to modify the sleep schedule and improvement in sleep hygiene should be attempted first. Medications could be tried to promote sleep but these should generally be used only short term. Wake-promoting agents may be appropriate in some conditions such as narcolepsy and shift work sleep disorder.[104] Other strategies that can be used are discussed in other sections of this document.

One of the common sleep disorders where an employer may institute a complete program is OSA. Treatment for mild OSA may include positional sleeping or oral appliance. For more severe cases, surgery such as mandibular advancement or uvulopalatoplasty may be indicated. The majority of OSA patients are treated with some form (continuous, auto-titrating, etc) of positive airway pressure (PAP). Diagnosis and determination of adequate pressure for treatment is generally conducted during a 2-night study. Some sleep specialists will utilize a "split night" procedure in which, if a high apnea hypopnea index is documented during the first half of a sleep night then continuous PAP (CPAP) is introduced and titrated during the second half of the study.[105] A recently introduced approach is the use of auto-titrating airflow generators that can significantly decrease the testing and titration duration.

Compliance

Ongoing compliance is a key component of successful treatment of a sleep disorder. Communication with the employee is essential. In individuals with OSA, long-term compliance rate is largely determined by the experience of the first few weeks. Modern PAP devices are designed to easily monitor compliance whether through downloading directly from the device or reading data from a removable memory card. The compliance monitoring may be provided by the organization that performed the polysomnogram or by a separate entity. Figure 9 represents the first-month activity of one approach that has resulted in an 84% adherence rate for CPAP.

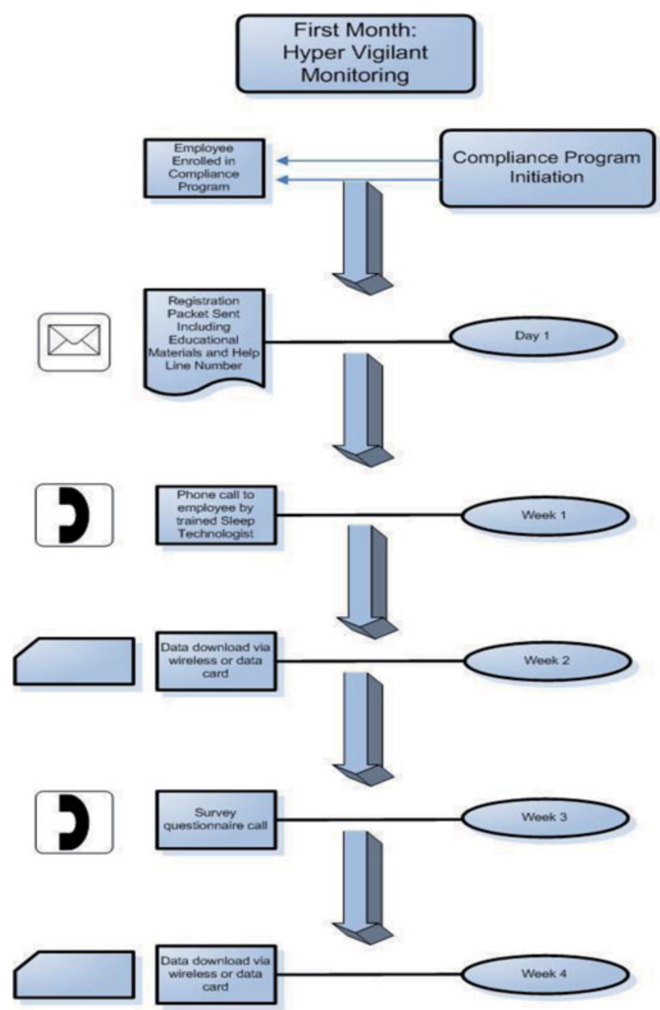

FIGURE 9. First month, hyper-vigilant compliance monitoring. With permission from University Services.

Some transportation companies have instituted OSA programs and have found a 30% reduction in accidents, $538 average per driver per month health care savings 12 months post-CPAP as compared with 12 months prior CPAP, and the employee retention rate doubled.[106] Another study projected $11.1 billion in collision costs and 980 lives a year saved by treating commercial drivers for sleep apnea.[107] Recommendations for screening, diagnostic treatment, and follow-up criteria, primarily for commercial drivers, that were endorsed by three medical societies, may be useful as considerations in a sleep apnea program.[108]

Defense 4: Work Environment

Key Points:

- The work environment can be designed to promote alertness.
- Light, temperature, humidity, noise, and ergonomic design can affect alertness.
- Schedule critical tasks at times of maximal alertness.
- Times of decreased alertness include end of any shift, early afternoon, and early hours of the morning.
- Day-shift recommendations for lighting remain unchanged.
- Bright night-shift lighting improves alertness and performance, but has adverse health effects, most likely due to melatonin suppression and other hormonal effects.
- Adverse health effects of bright night-shift lighting can be avoided by blocking light of wavelengths shorter than 480 nm.
- Breaks for exercise, conversation, and/or naps can be timed to enhance alertness; recommendations vary with time of day and type of task.

Measures to counter the risks associated with fatigue in the workplace include a range of personal, corporate, and regulatory strategies that have been discussed in the previous sections. Although employees must take personal responsibility and incorporate fatigue prevention strategies into their own lives, some fatigue may be unavoidable. For example, during work shifts occurring at the low point of the circadian cycle, fatigue is hard to prevent. Similarly, the occasional unavoidable situation will lead to an employee reporting to work in a sleep-deprived state.

Once the individual is at work, the range of strategies available to counter fatigue is limited and, in general, does not address the underlying physiological causes of fatigue. Instead, these strategies are meant to create a workplace environment that is conducive to alertness and attention to task, or to enhance performance temporarily so that operational safety and efficiency are maintained. The goal is to improve alertness and performance when compared with the baseline condition in which no countermeasures are taken.

Interventions to be discussed in this section, called operational countermeasures by some authors, address the workplace environmental conditions and work task parameters that have been shown to impact fatigue, alertness, and performance. These include the following:

- Environment—light, temperature, humidity, and sound
- Activity—breaks from sustained work activity
- Influence of the work itself in terms of mental (monotonous vs stimulating) and physical (strenuous vs sedentary) demands, ergonomic design, and postural factors

Alertness and vigilance have been shown to be affected by environmental factors such as light, temperature, and noise, as well as by task parameters such as monotony.[109] Workplace operational countermeasures commonly used to enhance alertness include control of environmental factors such as the intensity and wavelength of lighting, sound levels, temperature, and humidity.

Unless the nature of the work does not permit it, workspaces should be brightly lit, utilizing indirect lighting to avoid glare and eye strain. Indoor temperature and humidity should be controlled within a comfortable range, with environmental temperature at the lower end of the comfortable range. Company policy should incorporate allowing self-selected and/or scheduled breaks for physical activity, social interaction, and food and beverage consumption.

The physical and mental demands of work have also been shown to influence fatigue and alertness. The opportunity for breaks should, therefore, be based in part on the nature of the work that is being done. Heavy physical activity may be more fatiguing and require more breaks than lighter activities. On the contrary, workers performing work that requires constant vigilance may need breaks to maintain their ability to sustain attention. Workstation physical design must utilize good ergonomic principles to reduce fatigue associated with repetitive strain or to prevent musculoskeletal fatigue from static postures.[110–112]

Light

Recommendations for workplace lighting during day and night shifts are significantly different because of the sensitivity of the human circadian system to nocturnal light. For day shifts, the standard recommendations for workplace lighting apply. Workspaces should be brightly lit, utilizing indirect lighting to avoid glare and eye strain. Light levels should be adequate for the performance of the required job tasks without risk of eyestrain and should be adequate to enable safe movement around the workplace. The extent of natural lighting, the reflective properties of materials in the work area, the nature of tasks being undertaken, and the age of the workforce must be taken into account when designing workplace lighting for the day shift. A combination of direct and indirect lighting (eg, uplighting) will help reduce glare and areas of shadow.[112]

During overnight shifts employees are much more sensitive to light, especially during the "window of circadian low" between approximately midnight and 6 AM in individuals synchronized to day work and nocturnal sleep. There are three important effects of nocturnal light that can cause a mixture of desirable and undesirable outcomes: (1) phase resetting of the circadian clock; (2) stimulatory effects that directly increase levels of alertness, vigilance, and performance; and (3) increased health risks secondary to effects of nocturnal light exposure on neuroendocrine systems. These make the recommendations discussed later for lighting on the night shift more complex. Fortunately, recent research has shown that many of the adverse effects of light exposure at night are wavelength specific. This offers an opportunity to obtain the benefits of nocturnal lighting without the adverse health consequences.

Effects of Exposure to Light During the Night

1. ***Phase resetting*:** A single exposure to bright light (>5000 lux) for 3 to 5 hours during nocturnal hours or multiple lower intensity exposures over several nights, either delays the human circadian clock (ie, the onset of sleepiness) in the first half of the biological night or rapidly advances the circadian clock (ie, hastens the increase in alertness that normally occurs in the morning) when the light exposure is in the second half of the night. Because human alertness and performance reaches a nadir during the window of circadian low, Czeisler et al[113] proposed this as a technique to accelerate adaptation to night work by shifting the circadian rhythms of alertness and performance. This 5000 lux of illumination is, however, quite low compared with natural outdoor lighting levels, which range from more than 100,000 lux on a bright sunny summer day to about 10,000 lux outside on a dark, cloudy day. However, the 5000 lux level is bright when compared with most artificially illuminated nocturnal work places that provide 50 to 200 lux or even less.

Czeisler's study[113] demonstrated that when night workers were exposed to bright light (7000 to 12,000 lux) during night shifts and to darkness during daytime, their alertness, mood, and cognitive performance were significantly improved during night-shift work. However, a major complaint about the use of bright light was that it made the readjustment to a daytime schedule after night work more difficult. This represents a significant issue, because most individuals working the night shift still revert to daytime family and social activities on their days off. Other drawbacks are that the technique is hard to implement in many work environments, is not well accepted by shift workers, and is relatively expensive to implement.[111] An alternative technique for phase resetting is to use dark sunglasses while driving home after night shift to prevent affecting circadian rhythm due to exposure to natural bright morning light.[114–116] Although this technique can only achieve partial phase resetting, it has been shown to improve sleep and alertness. However, readjusting back to day shifts and night sleep is still difficult.

2. ***Stimulatory effects*:** Light also has direct stimulatory effects that do not involve circadian clock resetting.[117] Illumination that is 750 to 1000 lux, reverses the normal fall in alertness that occurs during the night shift as compared with exposure to 100 lux.[118] For example, Fig. 10 shows that individuals exposed to 1000 lux during simulated night shifts were less likely to fall asleep on the job. They also scored better on cognitive performance tests than workers exposed to less light. Over the past 20 years, as computer display screens have become progressively more common in the workplace, the tendency has been for nocturnal workplaces to become progressively darker, because the visual display is sharper in dimmer room light, and the computer screens may reflect bright room light sources in a distracting and stressful way.[119] This especially occurs when night workers have control of the dimmer switch. The research on the effects of light on alertness and performance has led to recommendations to reverse this trend and to make nocturnal workplaces well lit.
3. ***Adverse health effects*:** In the last 10 years, enthusiasm for increasing the brightness of illumination of the nocturnal workplace has dampened as evidence has accumulated that exposure to light at night has adverse health consequences. Nocturnal light exposure and frequent circadian rhythm disruption is common in nighttime shift work and has been identified as a risk factor for some life-threatening pathologies such as cancer,[120] heart disease,[121] and metabolic disturbances.[122–125] Light exposure at night has widespread neuroendocrine effects including suppression of melatonin and elevation of cortisol.[126,127] Light-induced melatonin suppression has been associated with an increased risk of cancer in shift workers, according to the International Agency for Research on Cancer. In 2008, the International Agency for Research on Cancer classified shift work as "a probable carcinogen," and suggested this was related to light-induced melatonin suppression.[128] Light at night causes cortisol to be elevated, which can cause insulin resistance, resulting in an increased risk of diabetes and metabolic syndrome. Light exposure during the night also increases the risk of suffering obesity.[129] Exposure to light can also increase heart rate, suggesting an impact of light on the autonomic nervous system.[130] Hypertension, hyperglycemia, and decrease in the appetite-regulating hormone leptin have been observed with light exposure at night.[28] The emerging data on the nocturnal light-mediated health risks of shift workers over the last 10 years have created a quandary on the lighting conditions that should be recommended for the night shift. As shown in Table 3, the benefits of increasing nocturnal light are largely safety and performance related, whereas the risks are primarily health related.

Innovative Approaches to Nighttime Lighting of Work Spaces

New research from Casper et al, at the University of Toronto[131,132] provides an intriguing and relatively simple solution to obtain the benefits of bright light without the risks. In nocturnal workplace environments that are continuously lit, the melatonin suppression and circadian resetting effects of bright light are limited to a very narrow band of wavelengths in the blue part of the light spectrum. As shown in Fig. 11, the human visual spectrum extends from violet (380 nm) to red (700 nm).[133]

In experiments using notch filters in rodents, the effects of light on melatonin suppression, cortisol elevation, and circadian clock gene markers were found to be restricted to a narrow wavelength band between 470 and 480 nm.[131] This was confirmed in human subjects by showing that the use of light filtering glasses with a sharp cutoff in light transmission below 480 nm prevented the effects of light exposure at night on melatonin, cortisol, and clock gene expression, whereas placebo glasses with a cutoff at 460 nm did not.[132]

Studies in shift workers show that it is now possible to get the beneficial effects of brighter light at night without the disadvantages. Field trials in shift work operations (hospital nurses and nuclear power plant operators) show that when sub-480 nm light wavelength are filtered out by using eyeglasses with specially designed wavelength filters (called Zircs™), the resetting effects of light on the circadian system were blocked and significant improvement in alertness, sleep, and mood were observed.

Temperature and Humidity

Other environmental countermeasures commonly employed include keeping ambient temperature cool and humidity low. Research studies dealing with the effects of ambient temperature on performance are relatively contradictory, unless they consider the

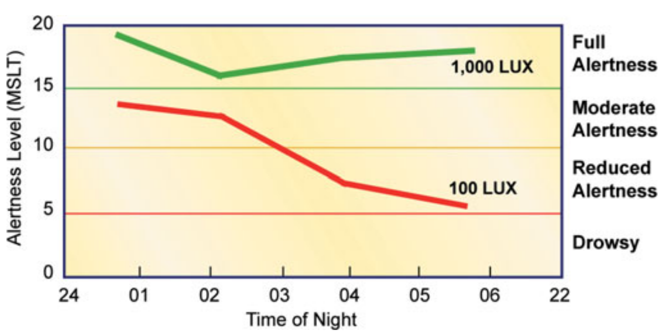

FIGURE 10. Alertness is sustained throughout a night shift by 1000 lux, but not 100 lux of illumination. Reprinted with permission from Campbell and Dawson.[118] Copyright 1990, Elsevier.

TABLE 3. Summary of the Benefits and Concerns of Using Bright Light at Night in Nocturnal Workplaces

Benefits	Concerns
Increased alertness/ reduced sleepiness	Shift biological clock/ disrupt sleep
Increased vigilance	Elevation of cortisol, insulin resistance, obesity metabolic syndrome
Improved cognitive performance	Suppression of melatonin and "probable" carcinogenic risk

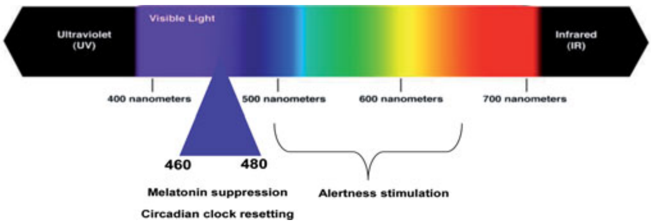

FIGURE 11. Narrow spectral band (460–480 nm) responsible for melatonin suppression and circadian clock resetting in continuously illuminated nocturnal workplaces, but not for alertness stimulation effects of light. Reprinted from Moore-Ede et al[133] by permission of CIRCADIAN®.

type of tasks.[134] Ambient temperature seems to have a significant impact on performance and alertness via induced changes of internal body temperature. Exposure to high environmental temperature (>28°C/82.4°F) reduces alertness when performing both cognitive and vigilance tasks. However, very few studies exist on the use of ambient temperature as a means of enhancing alertness.

In addition to air temperature, the degree of ventilation, humidity, and location of radiant heat sources will all affect worker comfort. Recommendations are that indoor temperature should be controlled at the lower end of the comfort range and humidity should also be controlled within a comfortable range. The Workplace (Health, Safety and Welfare) Regulations 1992 Approved Code of Practice recommend a minimum temperature of 16°C (60.8°F) or 13°C (55.4°F) if the work involves severe physical effort.[112] A maximum temperature for indoor workplaces is not specified; the low end of comfort 20°C (68°F) is generally chosen as a warm, stuffy atmosphere can cause drowsiness.

To some extent, increased ventilation may also be used as a means to maintain alertness. The opening of a car window while driving is one of the most frequent methods used by motorists to counter sleepiness. This technique seems to be short term; it serves as a temporary solution until a break is possible.[111] Monitoring workplace temperature on a regular basis allows adjustments to be made for particular shifts. Where maintaining a comfortable temperature throughout the workplace is impractical, it may be best to allow workers to control local heating and cooling arrangements.

Sound (Noise, Music, Conversation)

Studies of the effects of noise on performance have been primarily conducted in laboratory settings. Sound can be sedating (continuous droning/humming) or stimulating (music of varying tempos, conversation) in its effect (California OSHA Web site). In practical application, allowing for social interaction and providing other patterns of nonmonotonous sound can contribute to enhancing alertness.[135]

Noise may ameliorate performance decline due to circadian cycle effects by increasing the general level of arousal. This effect is dependant on variables such as the nature of the noise, the nature of the task, the time of day, and on personal factors. In one study, the continuous generating of 75 dB noise counteracted the sleep inertia following napping during the first part of night (from 1 to 2 AM) and had a positive effect on subsequent cognitive performance.[136]

Studies on motorists have shown that exposure to noise, or to a combination of noises, may be a good means of countering sleepiness and fatigue. Truck drivers participated in a field study of a waking sound system. The system was based on sound that varied in duration and frequency. Exposure to the sound was correlated to improvements in self-reported wakefulness. The sounds were not felt to be annoying.[137] However, noise is not always beneficial. It may produce decrements in performance if task demands are heavy or if the noise is loud enough to obscure signals from instruments or coworkers' speech. Exposure to noise for an extended period of time may produce subjective feelings of unpleasantness and an increase in complaints of fatigue.

Music is the countermeasure most frequently used in the workplace. Studies have shown that background music improves workers' performance in general. It has an advantage as compared with noise: performance, even at the same sound intensity, is better, and most workers find background music more acceptable. Most studies of background music versus no music show beneficial effects on vigilance. Music, even of low intensity, seems to prevent performance decrements over time and to help maintain alertness when sustained attention is required.[111] However, as with noise, the stimulant value of music is related to its characteristics: the more varied the sound, the more stimulant the effect. These effects vary between individuals and tasks. As an example, listening to the car radio while driving is another frequent method used by motorists to counter sleepiness. As with ventilation, the efficiency of this technique seems to be short term; it serves as a temporary solution.

Ergonomics

Ergonomics is a term derived from the Latin words *ergo* (meaning work) and *nomos* (meaning law) and is generally described as the science of fitting the job to the worker. Variability in human anatomy, physiology, and psychology creates challenges in designing an optimal work environment for the greatest number of workers. Ergonomics uses information about human abilities and limitations to ensure that equipment, work, and workplaces allow for such variability.

Designing tasks, equipment, and workstations to suit the user, rather than requiring the user to adapt to the equipment, can reduce human error, accidents, and ill health. Environmental conditions (light, temperature, humidity, noise), work activity demands (from sedentary to heavy physical activity and monotonous to varied), and rest breaks can also be considered as part of an ergonomic design. The publication of the National Institute for Occupational Safety and Health (NIOSH) on *Elements of Ergonomics Programs: A Primer Based on Workplace Evaluations of Musculoskeletal Disorders* describes the basic elements of a workplace program aimed at preventing work-related musculoskeletal disorders. NIOSH ergonomics investigations are used to illustrate practical solutions, and the primer includes a collection of techniques, methods, reference materials, and sources for other information that can help in program development.[138]

Task Parameters

The nature of the task itself affects alertness. Although monotonous and boring work may contribute to sleepiness when fatigued, performing more stimulating but critical tasks while fatigued may result in a higher risk of adverse outcome. Concentration and productivity tend to decline in the early afternoon, during the early hours of the morning, and toward the end of any given shift. It is, therefore, desirable to schedule critical tasks to be performed while workers are most likely to be alert (during day shifts or early in a night shift).

Variation in work activity across a shift can help to relieve fatigue, especially where the worker has a range of tasks to complete, each with differing mental and physical demands. Rotating routine sedentary mental tasks with physical tasks can promote alertness or conversely help to relieve physical fatigue. Where it is possible, workers should be allowed some choice regarding the order of completion.[112] Administrative countermeasures include the following:

- confining higher-risk activities to times when two or more people are present;
- avoiding higher-risk activities during the low point in the circadian alertness (3 to 5 AM);
- avoiding individuals working alone and maintaining communication at all times; and
- implementing checklists and double checks for higher-risk tasks.[139]

Work Breaks

Operational countermeasures also include allowing frequent and regular breaks from work tasks to reduce the risk of fatigue. Short breaks for physical activity, social interaction, and food and beverage consumption improve alertness and performance. Breaks may be scheduled and/or self-selected. Ideally, workers would be allowed to rest before they experience fatigue. Depending on the nature of the work, allowing workers choice about the frequency, and duration of the breaks may reduce fatigue and increase productivity.

When work is out of the workers' control (machine-paced rather than self-paced), frequent rest breaks must be preplanned into the schedule. Workers may benefit from more frequent breaks toward the end of a shift because the risk of fatigue is higher toward the end of a shift. Injury risk increases as the time interval between breaks increases, therefore, shorter, more frequent (3 to 4 per 8-hour shift) breaks may be more beneficial than 1 or 2 longer breaks (Cal OSHA). Frequent short breaks of 5 to 15 minutes every 1 to 2 hours have been shown to reduce fatigue, improve productivity, and reduce the risk of errors or accidents, especially when the work is either demanding or monotonous. Thus, the opportunity for work breaks should be based in part on the nature of the work that is being done.

Heavy physical activity may require more frequent breaks than lighter activities to prevent fatigue. Workers performing sedentary work that requires constant vigilance, on the contrary, may need frequent breaks to help prevent attentional failures (described anecdotally as being on "autopilot") or performing tasks without adequate conscious attention.[110–112]

Breaks taken away from the work station and/or work environment have been found to be more beneficial than those taken at the workstation.[112] Social interaction and conversation can be a useful operational strategy to enhance alertness. However, the individual must be actively involved in the conversation, not just listening. In fact, some studies have indicated that the lack of conversation is a predictor of declining physiological alertness.[110]

Sleep-deprivation experiments have shown that physical activity is one of the most effective ways of combating sleepiness. Getting up and walking or stretching are common ergonomic interventions recommended for those involved in sedentary work. Stretching and isometric exercises can be done even while seated; writing or chewing gum may help a drowsy person stay awake.

Conversely, because of its potentially stimulating effects, shift workers are advised to avoid physically strenuous activity for a couple of hours before their usual bedtime.[140] The role of physical exercise in resetting the circadian clock has been investigated in animals, and the pattern of resetting is similar to that observed with light: Exercise in the morning advances the circadian clock, whereas exercise in the evening delays it.[110] There is some evidence of similar circadian effects in humans. Therefore, the optimal time for exercise during the night shift seems to be early in the shift, specifically between midnight and 2 AM, for the maximum maintenance of alertness and delay of sleepiness.[141]

Food

Work schedules can also make it difficult to maintain a regular pattern of well-balanced meals. During the night shift, the main meal should be eaten around 1 AM and consist of high-protein, complex carbohydrate, and low-fat foods. Gastrointestinal upsets can be disruptive to sleep, and large meals should not be eaten before morning bedtime.[142]

Naps

Brief structured nap breaks during extended-hour work shifts have been shown to be an effective operational strategy. Both objective physiological measures and subjective ratings of alertness demonstrate improvement following a nap taken during periods of sustained wakefulness. Naps can also reduce or delay expected performance decrements.[143] A joint study by the National Air and Space Administration (NASA) and the Federal Aviation Administration examined the effect of a planned cockpit rest period during long-haul flights. Two crews flying the same sequence of four scheduled flights were compared. One group was allowed a 40-minute nap opportunity (one crew member at a time), whereas the other group followed their normal activities. Crew assigned to the nap group showed better performance and higher physiological alertness on objective measures during the last 90 minutes of the flight than did the control group.[110]

In a study of paramedics, a modified night-shift schedule design ensured time to nap and resulted in decreased subjective fatigue and improved physiologic function.[144] The authors point out that the facilities for napping were private and postulate that dormitory-type facilities may be less effective due to the potential for disturbed sleep when other employees are awake. First-year physicians in training experienced decreased fatigue when assigned to an overnight call schedule that included physician coverage for a nap break.[145]

However, napping during a regularly scheduled break while at work is a controversial area. Sleeping while at work can be an unacceptable practice to both to employers and employees. Some employers have employment policies that specify sanctions, including termination of employment, for employees found asleep on the job. Some employees also find this unacceptable; in a study of implementation of an FRMS for hospital nurses, many participants did not find this an acceptable strategy.[146] Therefore, if included as a countermeasure in an FRMS, a specific policy and structured protocol for implementation must be developed. Staffing must, of course, be adequate to maintain operations during the time allowed for napping.

Timing and duration of naps can be designed for optimal impact on alleviating fatigue. An important consideration in terms of scheduling is the duration of the beneficial effects obtained. Studies suggest that a nap can maintain or improve subsequent performance and physiological alertness from 2 to 12 hours following the nap.[143] Another scheduling issue is the time allotted for a nap break. Experiments have examined naps of varying lengths, and there seems to be a dose-dependent effect: More sleep is associated with greater beneficial effects. However, some studies suggest that shorter naps can be just as or more effective than longer ones; recommendations range from 20- to 60-minute duration.[143,147,148] Shorter naps are also less likely to be associated with the phenomenon of sleep inertia (a short period of impaired alertness upon awakening).[112] This can be associated with a performance decrement lasting for a few minutes to 35 minutes, though effects usually seem to dissipate in about 10 to 15 minutes. Sleep inertia may be a consideration when an employee is likely to have a nap interrupted by an emergency requiring a quick response with a high level of performance. In such circumstances, time allotted for a scheduled nap should not exceed 30 minutes.

The potential benefits of a nap in improving alertness and performance during routine operations, with a resulting increase in safety margin, may outweigh the potential negative effects of a short period of sleep inertia.[143] A second potential negative consequence is that the nap can theoretically disrupt the duration or quality of a later sleep period. Providing fatigued employees with an opportunity for a nap before driving home at the end of a shift will theoretically decrease the risk of accidents while driving fatigued. However, because employees may not be reliable judges of their level of fatigue, this option may rarely be utilized.

Defense 5: Individual Risk Assessment and Mitigation

Key Points:

- Employees, coworkers, and supervisors should be alert to signs of excess fatigue.
- Supervisors should have the responsibility and authority to mitigate the fatigue or the safety risk of the fatigue.
- Mitigation steps include immediate actions such as encouraging a rest break.
- Repeated bouts of fatigue require additional steps that may include referral for medical evaluation.
- Fatigue monitoring devices exist but are not yet widely deployed.

Identifying and Mitigating Employee Fatigue

As previously noted, employees should be encouraged to monitor their own level of fatigue and inform their supervisor if they believe that they are too fatigued to safely perform their work. Knowledge of how to recognize fatigue is a component of the training that employees should receive. Employees will be much more likely to bring these matters to the intention of their supervisor if the organization succeeds in creating a "just culture."

Increasingly, organizations are deploying behavior-based safety programs, a key component of which is peer-to-peer safety observations.[149] These programs are designed to promote a safety culture in which identifying unsafe acts or conditions and bringing them to the attention of a coworker is viewed as helping that colleague stay safe, rather than as meddling in another's business. This concept should be extended to include identifying signs of excessive fatigue among coworkers. Supervisors in particular have a responsibility to be alert for signs of excessive fatigue among their staff. The supervisor training module should provide additional training on the recognition of excessive fatigue (Table 4).

Once supervisors become aware of the possibility of excessive fatigue, they should take appropriate action to mitigate the fatigue or the safety risk of the fatigue. The specific strategies that can be used depend on the nature of the work, the individual, and the company; however, they may include the following[36]:

- Taking a break: this will tend to be more effective if it is combined with moderate exercise such as taking a walk.

TABLE 4. Signs of Excessive Fatigue

Physical signs
Yawning
Drooping eyelids
Rubbing of eyes
Head dropping
Microsleeps
Digestive problems
Mental signs
Difficulty concentrating on tasks
Lapses in attention
Difficulty remembering tasks being performed
Failing to communicate important information
Failing to anticipate events or actions
Accidentally doing the wrong thing
Accidentally not doing the right thing
Emotional signs
More quiet or withdrawn than usual
Lack of energy
Lacking the motivation to perform the task well

- Shifting safety-sensitive activities to others who are more alert or to another time.
- Utilizing a buddy approach to increase social interaction and help monitor alertness.
- Appropriate use of caffeine. Caffeine, if used, should be consumed in moderation. It takes approximately 30 minutes for it to take effect. If possible, a caffeinated beverage followed immediately by a brief nap can help restore alertness. Because caffeine's stimulating effects can last for as long as 6 to 8 hours, it should not be consumed in the hours before sleep is planned.
- Enhancing environmental factors such as lighting and music as described in the section dealing with "Defense 5."

Addressing Repeated Bouts of Fatigue

Repeated bouts of fatigue may occur for a variety of reasons. The employee may simply not be taking appropriate steps to ensure that they come to work rested and fit for duty. Rather than obtaining adequate sleep, they may be burning the candle at both ends, trying to hold down additional employment or participating in hobbies or social interactions at the expense of sleep. However, repeated bouts of excessive fatigue may be due to medical or psychosocial disorders. Supervisors should coach employees on the importance of reporting to work rested and alert. They should remind the employee of the fatigue training and provide written or computer-based refresher information.

Many organizations have employee assistance programs to provide psychological and psychosocial counseling. Employees should be reminded of this resource and encouraged to use it if appropriate. If there is reason to believe that they may have a medical or psychological condition that is impairing their fitness for duty, they should be sent to the organization's medical department or occupational health clinic for a fitness-for-duty evaluation. The fitness-for-duty evaluation may require referral for evaluation by a sleep medicine or other appropriate specialist.

Fatigue Monitoring Technologies

Even with appropriate training, individuals are not particularly good at assessing their own level of fatigue.[150] Supervisors may interact with an employee only *periodically* throughout a shift and supervisors' level of confidence and competence in detecting fatigue will undoubtedly vary. Thus, it would be desirable to implement an objective, real-time measure of fatigue and alertness.

There are a variety of tools designed to meet this objective. Many of these tools have been designed specifically for vehicle operators,[151] and generally fall into one of the following two categories:

1. Operator monitoring technologies provide a real-time observation and analysis of operator behavior and/or physiology such as eye closure, head position, or brain-wave activity.
2. Performance assessment technologies monitor tasks such as lane tracking and vehicle speed.

Other tests are designed to assess fatigue and alertness independent of the task being performed. Investigators at the Walter Reed Army Institute of Research evaluated a variety of such tools assessing their sensitivity, reliability, content validity (how well the test results track sleep impairment), and ease of use.[83] They concluded that the psychomotor vigilance test, which measures reaction time, compared favorably with the other tests they evaluated.

It should be noted that although real-time objective assessment of fatigue is very promising, it is not widely used in the field. It is likely that field trials would be needed to validate their use in an organization's specific circumstances. Issues to consider include the following:

- When would the test be administered (eg, pre-shift, every few hours, when a supervisor had concerns about fatigue, randomly)?
- Would participation be mandatory or voluntary?
- Who would obtain test results?
- What actions would be taken based on the results of the test?

Until these issues are resolved, the utility of such tools is limited.

ESTABLISHING CONTINUOUS FRMS IMPROVEMENT

Key Points:

- Incident investigation should be designed to collect adequate information regarding the involved employee(s) state of fatigue.
- Major areas to investigate include operator status, schedule assigned, medical factors, and type of incident (fatigue related or not).
- Investigators should be trained to assess the contribution of fatigue to a given incident.

Incident/Near-Miss Investigation

When evaluating an incident that may be due to fatigue, the two major steps are first to evaluate if the individual was susceptible to fatigue and second to evaluate whether the performance, behavior, and details of the event would be consistent with inaction or inattention.[16,151] All of the details mentioned later may not be required in all cases, but if initial evaluation suggests the incident may be fatigue related, then to completely assess the relationship, as much information as possible should be obtained. In some settings, it may be difficult to obtain some of the information. Evaluating a series of incidents that may be fatigue related may reveal aggregate data suggestive of the role of fatigue that may not be apparent from evaluation of a single incident.

It is important to focus not only on the individuals directly involved in the incident, but also on those who may have contributed to errors upstream. An example might be the mechanic who did not properly inspect or repair a vehicle, leading to a mechanical failure 2 days later. However, it should be noted that the further in the past these events occur, the more difficult it will be to obtain reliable information. Individuals who are evaluating whether fatigue could have contributed to an incident should be properly trained to do so. Currently, most accident reports rely on subjective reports of sleepiness or fatigue and determinations are only as good as one's understanding of the interplay of the multiple issues. Determining that the individual was susceptible to fatigue should not support fatigue as a cause or contributing factor to the incident unless the behaviors are also consistent with fatigue. Thus, it is necessary to determine whether performance decrements may have been responsible for the incident, whether tasks or parts of tasks were overlooked, or whether the focus was on one task while other important information was ignored. If the incident involved a vehicle, was there steering or speed variability? Finally, evaluate whether there was evidence of impaired decision-making or an inability to adapt behavior when new information became available. Interviews with coworkers or witnesses or audio or video recordings may help determine whether the appearance or behavior prior to the event was consistent with fatigue or sleepiness.

Operator-Related Factors

There are several operator-related factors that should be considered in as much detail as possible when evaluating a potential fatigue-related incident:

- sleep patterns—regular and any recent changes;
- sleep–wake durations—duration of sleep in the 72 hours prior to the incident and hours awake at time of incident;
- sleep disruption;
- work schedule issues—hours on job at the time of incident and overtime in the last 7 days;
- work time for at least the previous 7 days;
- start time of work shift;
- time of day the incident occurred;
- circadian factors;
- sleep or other medical disorders; and
- medications.

The individual's normal sleep habits, as well as the sleep–wake patterns for the preceding 72 hours, should be evaluated. The normal bedtime, time of awakening, and quality and quantity of sleep, including on days off, should be ascertained. Focus should then turn to the night before the incident as well as the 3 nights prior. Whether the individual napped, and if so, where, when, and for how long should be determined. Corroboration of the sleep–wake history should be obtained if possible by interviewing family members, coworkers, or others who may have knowledge of the incident. Receipts, cell phone records, log books, and work schedules should also be reviewed to corroborate the sleep–activity reports. It should be determined how many hours the individual had been awake at the time of the incident. Consideration should then be given as to whether the individual normally has disturbed or fragmented sleep and especially whether the sleep was disrupted in the days leading up to the incident. The individual and others should be asked whether there are environmental factors that may have disturbed the sleep such as noise, phone, lights, etc.

Schedule-Related Factors

Once the normal sleep pattern and the sleep pattern in the days before the incident is determined, attention turns to circumstances surrounding the incident, time of the incident, the number of consecutive shifts worked, and the shift duration (normal operations or an extended or overtime shift). It should be determined whether the event occurred during a circadian low point (either midnight to 6 AM or a secondary low point generally occurring between 3 and 5 PM). Also, consider whether the individual may suffer from a circadian rhythm disturbance such as crossing multiple time zones or working rotating or variable work shifts.

Medical-Related Factors

The final operator factor to evaluate is whether medical conditions or medications may have contributed. The OEM physician should inquire about a history of sleep disturbances—difficulty falling or staying asleep. Also, review the medication history, those used on a regular or intermittent basis and those used in the days prior to the incident. Use of both prescription and over-the-counter medications should be reviewed, through history and medical/pharmacy records. If available, toxicology results should be reviewed; if indicated, the individual should be evaluated by a physician who specializes in sleep medicine.

Tools to Determine Fatigue Causation Probability

Two sample checklists on establishing the fatigued state and the link between fatigue and the unsafe act/decision were developed for the Federal Transit Administration (Table 5 and Table 6).[152] Programs are available that can estimate whether a person was impaired by fatigue at the time of an accident or incident (eg, the Fatigue Accident/Incident Causation System)[153] or which can retrospectively analyze operator alertness and performance using mathematical algorithms. These algorithms analyze the amount of sleep obtained or missed, circadian factors, present workload, and related temporal antecedents of fatigue, to determine whether the individual was at risk of fatigue at the time of the incident. Examples are the Sleep, Activity, Fatigue, and Task Effectiveness model,[80] the Fatigue Avoidance Scheduling Tool,[80] the Fatigue Audit InterDyne,[81] the Circadian Alertness Simulator,[82] and others.

IDENTIFYING, COLLECTING, AND ANALYZING METRICS FOR FRMS

Key Points:

- Demonstrate the effectiveness of FRMS by collecting supporting data: attendance, safety, and health metrics.
- Identify one or more tools (eg, the Occupational Fatigue Exhaustion Recovery questionnaire) to use at intervals to assess the amount of workforce fatigue.

As previously noted, the API published *ANSI/API Recommended Practice RP755 Fatigue Risk Management Systems for Personnel in the Refining and Petrochemical*

TABLE 5. Investigation Procedure Checklist 1—Establishing the Fatigued State*

Issue	Probes	Desirable Response	Notes
Quantity of sleep	What was the length of last consolidated sleep period?	7.5–8.5 hr	
	Start time?	Normal circadian rhythm, late evening	
	Awake time?	Normal circadian rhythm, early morning	
	Was your sleep interrupted (for how long)?	No	
	Have you had any naps since your last consolidated sleep?	Yes	
	Duration of naps?	Had opportunity for restorative (1.5–2 hr) or strategic (20 min) nap prior to start of late shift.	
Summary—establish whether or not there was a sleep debt	Describe your sleep patterns in the last 72 hrs. (Apply sleep credit system.)	Two credits for each hour of sleep; loss of one credit for each hour awake-–should be positive value.	
Quality of sleep	How did the sleep period relate to the individual's normal sleep cycle, ie, start/finish time? (See "Quantity of sleep.")	Normal circadian rhythm, late evening/early morning	
	Sleep disruptions?	No awakenings	
	Sleep environment?	Proper environmental conditions (quiet, comfortable temperature, fresh air, own bed, dark room)	
Summary—establish whether or not the sleep was restorative	Sleep pathologies?	None	
Work history	Hours on duty and/or on call prior to the occurrence?	Situation dependent—hours on duty and/or on call and type of duty that ensure appropriate level of alertness for the task.	
Summary-–establish whether the hours worked and the type of duty or activities involved had an impact on quantity and quality of sleep	Work history in preceding week?	Number of hours on duty and/or on call and type of duty that do not lead to a cumulative fatigue effect.	
Irregular schedules	Was he/she a shift worker?	No. (Shift workers never fully adapt in terms of sleep quantity.)	
	If yes, was it a permanent shift?	Yes—days	
	If no, was it rotating (vs irregular) shift work? How are overtime or double shifts scheduled?	Yes—Rotating clockwise, rotation slow (1 day for each hour advanced), night shift shorter, and at the end of cycle.	
	How are overtime or double shifts scheduled?	Scheduled when operators will be most alert in the context of their circadian rhythm.	
	Scheduling of critical safety tasks?	Scheduled when operators will be most alert in the context of their circadian rhythm.	
Summary—establish whether scheduling was problematic with regards to its impact on quantity and quality of sleep	Is there a fatigue countermeasure program in place?	Yes.	

*Adapted from Gertler et al.[152]

Industries in April 2010.[66] This standard was developed specifically for the petrochemical industry but provides guidelines for the development and implementation of an FRMS that may be adapted by other 24/7 industries. One of the recommendations is that "key outcomes that may be impacted by fatigue (eg, absenteeism, health care costs, safety, and hazard loss data, including aggregate analysis of incident investigation results) should be monitored."[66] Multiple studies have documented the negative effect of worker fatigue on outcome parameters including safety, productivity, performance, accident rates, work-related injury, and employees' personal health.[4,34,95,154,155] Metrics commonly used to measure these outcome parameters include data collected from employer time and attendance systems, OSHA recordable incident log, work-related accidents, injury rates, and employee health care cost data. Systems for reporting and investigating accidents and injuries must be in place. The reporting process should be simple and straightforward and problems identified dealt with in a timely manner.

Identifying Metrics

When cases of ill health that may be associated with shift work are identified, an evaluation should be conducted by an occupational health professional to determine whether the complaint is actually related to work and who can provide treatment and advice on the potential for any long-term effects.[112]

Data should ideally be collected before the FRMS is implemented and then tracked periodically. This will help set measurable targets and identify if these have been met. Examples of indicators used to determine whether changes due to implementation of an FRMS have helped are discussed in this section; however, other measures more suited to a particular industry should be considered. A mixture of objective and subjective information may be helpful. Employer records on absence, overtime, accidents, productivity, and employee health are valuable sources of objective information. Assessment of how shift work characteristics affect a workforce may be done through the use of focus groups, survey questionnaires, interviews, and assessment tools.[139]

TABLE 6. Investigation Procedure Checklist 2—Establishing Link Between Fatigue and Unsafe Act/Decision*

Performance Impairment	Indicators	Notes
Attention	Overlooked sequential task element	
	Incorrectly ordered sequential task element	
	Preoccupied with single tasks or elements	
	Exhibited lack of awareness of poor performance	
	Reverted to old habits	
	Focused on a minor problem despite risk of major one	
	Did not appreciate gravity of situation	
	Did not anticipate danger	
	Displayed decreased vigilance	
	Did not observe warning signs	
Memory	Forgot a task or elements of a task	
	Forgot the sequence of tasks or task elements	
	Inaccurately recalled operational events	
Alertness	Succumbed to uncontrollable sleep in form of microsleep, nap, or long sleep episode	
	Displayed automatic behavior syndrome	
Reaction time	Responded slowly to normal, abnormal, or emergency stimuli	
	Failed to respond altogether to normal, abnormal, or emergency stimuli	
Problem-solving ability	Displayed flawed logic	
	Displayed problems with arithmetic, geometric or other cognitive processing tasks	
	Applied inappropriate corrective action	
	Did not accurately interpret situation	
	Displayed poor judgment of distance, speed, and/or time	
Mood	Was less conversant than normal	
	Did not perform low-demand tasks	
	Was irritable	
	Distracted by discomfort	
Attitude	Displayed a willingness to take risks	
	Ignored normal checks or procedures	
	Displayed a “don’t care” attitude	
Physiological effects	Exhibited speech effects—slurred, rate, content	
	Exhibited reduced manual dexterity—key-punch entry errors, switch selection	

*Adapted from Gertler et al.[152]

Examples of metrics include the following:

- Time and attendance data (absenteeism, hours worked, overtime) are measures often used to estimate productivity.
- Validated survey instruments such as the Work Limitations Questionnaire may also be used to assess productivity.
- The OSHA recordable work-related injury and illness data collection is required by federal regulation.
- Workers’ compensation injury and illness incidence, severity, and costs can be obtained through the workers’ compensation insurance carrier.
- Root cause analysis during incident investigation of an accident or injury can help identify whether fatigue was a contributing factor.
- Employee health status may be tracked through health risk assessments, health care insurance utilization data, health care cost data, and employee surveys or questionnaires.
- Employee fatigue or sleepiness at work may be measured by assessment tools such as Health and Safety Executive’s Fatigue and Risk Index Tool or the Epworth Sleepiness Scale.

Assessment of Fatigue

Numerous subjective and objective measures are available to assess fatigue and performance; these have mostly been used by researchers. Some such as the Epworth Sleepiness Scale are suitable for use in monitoring an employee population in a field setting. However, most currently available sleep disorder testing and neuropsychological testing will be performed in a laboratory setting.

The Occupational Fatigue Exhaustion Recovery scale has been developed specifically to measure work-related fatigue. This is a simple-to-administer, 15-item questionnaire that possesses robust psychometric characteristics, is free of gender bias, and has been validated in a major study. It consists of three subscales that can distinguish between chronic work-related fatigue, acute post-work fatigue and effective fatigue recovery between shifts. The Occupational Fatigue Exhaustion Recovery Scale is suggested as a potentially valuable new tool for use in work-related fatigue research.[156]

Absenteeism and Productivity

Rates of absenteeism in extended-hours industries range from 6% to 12% compared with the national average of about 2%. An absent worker in a 24/7 operation must either be replaced (often with someone paid overtime) or coworkers must pick up the slack (potential for fatigue, safety, and morale problems).[157] Absenteeism data collection and pattern analysis can help illuminate the root causes if the data include information such as shift, day of the week, and reason given by the employee.

Two recent studies examined the relationship of fatigue and productivity using validated standard questionnaires to measure productivity loss. A study of employees from four different industries used the validated Work Limitations Questionnaire to assess limitations in ability to work, lost productivity, and employer costs. Employees were surveyed about sleep patterns and classified into four groups (ranging from good sleep to insomnia). Work Limitations Questionnaire consists of four subscales that measure time management at work, performance (physical and mental), interpersonal interaction, and work output. Additional questions about memory, concentration, decision-making, and safety problems were developed for this study.

The poor sleep groups, about 15% of the total study group, had significantly worse productivity, performance, and safety outcomes.[33] The Caremark Work and Health Interview was used to assess lost productive time that includes both absence and decreased performance as well as associated health complaints that included fatigue. The prevalence of fatigue in the study population was about 38% and workers with fatigue reported health-related lost productive time more than twice as often as those without fatigue.[95]

Accident and Injury Rates

Another metric commonly collected by employers is accident and injury incidence rates. An increased risk of accident and injury has been reported in individuals working extended or night shifts. NIOSH reviewed research studies that examined the association between long working hours and illness, injury, health behavior, and performance.[4] Decreased performance and an increase in injuries were observed across studies to be associated with long hours. Studies have consistently shown that sleep deficit and fatigue have negative effects on objective measures of performance.[5,158]

Decreases in measures of vigilance, concentration, and judgment can lead to accidents, errors, and injuries.[159] Metrics on accidents, injuries, and errors are already collected in the form of OSHA 300 log reports, workers' compensation incidence data, and other company mandated safety or accident reporting systems. Some metrics may be industry specific. For example, health care institutions are required to track blood borne pathogen exposures. Extended work duration and working at night were associated with an increased risk of percutaneous injuries in a prospective cohort study population of almost 3000 physicians during their first year of clinical training.[160]

Another metric collected by health care institutions is medical error rates. Extended duration and night shift work have been associated with an increased incidence in medical errors and adverse outcomes for physicians in training.[161–163] Physicians in training also had more than double the risk of a motor vehicle crash when driving home from shifts lasting more than 24 hours than from shifts averaging 12 hours.[18] This is a well-known hazard in the transportation industry where numerous studies have examined the association between extended work hours, fatigue, and risk of accidents (motor vehicle, train, and plane crashes).

Health Effects and Costs

The association between extended duration shifts, sleep deprivation, fatigue, and adverse health effects has already been discussed. A NIOSH report reviewed studies that examined the association between long working hours and illnesses, injuries, health behaviors, and performance. In general, overtime was associated with poorer perceived general health, unhealthy weight gain, increased alcohol use, increased smoking, increased injury rates, more reported illnesses, increased mortality, and poorer neuropsychological test performance. Extended night shifts were associated with more physical fatigue, smoking, or alcohol use when compared with shorter or day shifts.[4]

A study of nurses found an increased risk for weight gain, cardiovascular illness, and gastrointestinal problems in shift workers.[164] A New Zealand study found that shift workers, particularly on rotating shifts, had a higher incidence of sick leave, a higher rate of clinic visits, and poorer scores on a variety of health measures, particularly digestive disorders and cardiovascular disease.[165]

Health care insurance utilization, prescription drug plan costs, worksite heath clinic visits, and sick leave are readily available metrics for analysis. Many organizations have also instituted health risk assessments to support and target employee wellness programming. These usually include questions on smoking, alcohol use, weight gain or loss, exercise, perception of overall health status, and presence of specific chronic illnesses. The health risk assessments should also include questions on work-related fatigue, job satisfaction, and interpersonal relations.

Periodic Review of the FRMS to Achieve Continuous Improvement

- Setting targets for key parameters of the FRMS.
- Metrics to determine whether those targets are being met.
- Audits and gap analyses.
- Closing any gaps between targets and actual FRMS performance.

One characteristic that distinguishes management systems from procedures is that all management systems include processes to periodically evaluate and improve the management system. One needs to identify the key parameters required for a successful FRMS in one's organization, identify a metric to quantify this, and define a target for performance. These metrics should include both leading indicators and lagging indicators and should be analyzed at least annually.

Leading indicators are measures of inputs. For instance, consider the question, "Is the target population receiving training, and is there evidence that they are absorbing the content?" For this metric, one would need to define the target population, track whether they have been trained, and measure comprehension (perhaps on a post-training examination). For example, in the first year of an FRMS, one might decide that success would be defined as 90% of the target population receiving training and that all trainees should obtain a score of at least 80% on a post-training examination.

Other leading indicators may include measures of staff-work load balancing (eg, percent overtime), measures of ability to conform to the hours of service guidelines (eg, number of exceptions), or effectiveness of a program to detect and treat sleep disorders (eg, percent of target population screened, percent of those screened that screen positive, percent of those screened positive who are referred for diagnosis and treatment).

If targets are not being met, one needs to determine the cause and institute measures to close the gap between the target and actual performance. If targets are being met, the targets themselves should be reevaluated to determine whether they can and should be tightened. For instance, if one set 90% as the target for completion of training in year 1, perhaps 95% would be an appropriate target in year 2.

Lagging indicators are indicators of outcome or effect. If the ultimate goal of an FRMS were to enhance safety, the ultimate measure would be safety performance and perhaps workers compensation costs. If these measures show a significant and sustained improvement after implementation of the FRMS, it may be safe to assume that the FRMS played a meaningful role. Conversely, if there is no discernable improvement in the first couple of years of a program, it is likely that the FRMS is not effective. A critical review of the leading indicators may identify the weaknesses in the FRMS.

However, many factors other than the FRMS may play a role in these outcomes. Thus, if the lagging indicators show a modest but positive trend, it can be very difficult to discern what if any role the FRMS is playing. A careful analysis of the incident investigation data, looking for patterns that may suggest that fatigue was a contributing factor in a number of the incidents, whereas more difficult is a more sensitive lagging indicator.

For instance, if a single incident occurred on the 10th or 11th consecutive hour worked, it may or may not be fatigue related. However, if 40% of all incidents occur after the 10th consecutive hour, that would be evidence that fatigue is not being optimally managed.

As important as metrics are to a robust management system, one can spend too much of one's time and effort measuring an FRMS at the expense of implementing it. There are several pitfalls to avoid in defining metrics, which are as follows:

- *Having too many measures*: Although, in principle, every component of an FRMS can be measured, one should identify those critical few measures that are likely to identify significant opportunities for improvement.
- *Having measures that are not feasible to obtain*: There may be metrics that would be helpful to track, but their collection is so resource intensive that it would divert attention from implementing the FRMS.
- *Having measures that are not meaningful*: Just as there may be useful data that cannot be obtained, there may be data that are tempting to be gathered because they are easily available, but that does not help evaluate the FRMS and identify continuous improvement opportunities. For instance, one may track how many work groups use each of several shift schedules. However, by itself, this information does not provide information on the effectiveness of an FRMS.

One of the advantages of a continuous improvement process is that it is less daunting to design and initiate an FRMS knowing that it need not be perfect the first time. Initiating the journey should result in decreased fatigue risk as well as increased employee health, morale, and productivity. A robust continuous improvement process will help ensure that these benefits grow over time.

CONCLUSION

Worker fatigue can adversely impact personal health and safety as well as the efficiency and safety of the operation. The most effective method to minimizing worker fatigue is through a comprehensive FRMS. An FRMS requires the active participation of all parts of the organization, including management, support functions, and workers. By promoting and participating in the development and implementation of an FRMS, OEM physicians can provide an important service to the organizations they support, those organizations' employees, and the communities in which they operate.

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