Staying Alert: Incorporating Human Fatigue in Risk Management

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This paper addresses the role of human fatigue in workplace safety and risk management. It is well known that fatigue can increase the likelihood of workplace injuries, but the systematic application of this knowledge in safety and risk management is less well known. This paper presents a risk-based method for addressing fatigue in safety and risk management processes. The method incorporates elements of a data-driven fatigue risk management system (FRMS). Specific issues include potential data sources for the FRMS and practical applications within existing safety management systems. Special attention is paid to the fatigue risk assessment, which mirrors a common safety risk assessment and affords systematic control of fatigue-related human error.

Introduction

Human fatigue is a peculiar issue in the field of applied human factors and in non-academic professions requiring safety and risk management. On one hand, imagining fatigue as a factor that can contribute to adverse safety incidents seems rational and intuitive, while on the other, managing fatigue risks in practice can prove to be quite challenging. Specific difficulties include, but are not necessarily limited to, realistic fatigue assessment; prioritization of work activities to be assessed and relevant fatigue hazards; and development of risk-assessable human-error scenarios that link fatigue hazards to adverse safety incidents.

The overarching goals for this paper are to review challenges of fatigue management and to present practical ways for applied human factors scientists and safety practitioners to approach them during risk management. The guidance applies to human factors specialists, health and safety professionals, managers, and frontline personnel tasked with demonstrating and promoting good safety performance. The content and methods offered here are based on scientific literatures and on professional experiences of the authors.

Basics of Human Fatigue

Human fatigue can be defined as a state of reduced mental or physical performance capability that results from (1) sleep loss, (2) circadian challenge, or (3) task factors (ICAO, 2011). The guiding framework for this paper holds that fatigue hazards within these three categories pose fatigue-related risks to an individual who is exposed to them and to the safety and function of systems with which that individual interacts. Fatigue risks precipitate mental and physical performance impairments, which can lead, in turn, to adverse incidents. The notion that fatigue can link hazards and adverse incidents gleans support from the history of catastrophic industry incidents, safety statistics, and scientific literatures.

Human Fatigue and Catastrophe

Multiple well-known catastrophes have been linked to fatigue. These incidents include the explosion and subsequent fire at the BP Texas City Refinery which killed 15 people and injured over 180 (CSB, 2007); nuclear releases at Three Mile Island and Chernobyl (Mitler et al., 1988); the breakup of Space Shuttle Challenger (Rogers et al., 1996); and the grounding of the Exxon Valdez oil tanker (NTSB, 1990).

An investigation by the US Chemical Safety and Hazard Investigation Board of the BP Texas City incident found that the board operator had worked 12-hour shifts for 29 consecutive days and suggested that fatigue-related human error contributed to the accident (CSB, 2007).

The Three Mile Island release occurred, in part because of human errors in recognition and corrective action in the early hours of 0400 – 0600 (Mitler et al.). The Chernobyl incident also began in the early-morning hours as the result of human error (Mitler et al.). Though limited information about specific human factors elements related to fatigue in these incidents makes it difficult to draw firm conclusions about how fatigue affected performance, the events remain generally consistent with research showing that the time period of approximately 0100 – 0600 hours is associated with increases in human error (e.g., Bjerner, Holm, & Swensson, 1955). Also, in the authors' incident investigation experience, catastrophic incidents often occur during overnight hours.

In its evaluation and description of pressures on the overall system for preparing and launching Space Shuttle Challenger, the Rogers Report noted that support workforces became increasingly strained as the turnaround time decreased to accommodate the accelerated launch schedule and connected this problem to another serious incident that occurred during a previous launch attempt; the report noted fatigue, shiftwork, and overtime as contributing factors (Rogers et al., 1986). Finally, the National Transportation Safety Board (NTSB) concluded that the Exxon Valdez tanker grounding entailed fatigue, workload, reduced crew size, and insufficient rest as contributing factors (NTSB, 1990).

Statistics also indicate that fatigue poses significant risks for death and injuries. It is estimated that (a) 360,000 worldwide workplace fatalities occur per year, (b) 960,000 workplace injuries occur per day, and (c) about 13% of these injuries can be attributed to fatigue (Uehli et al., 2007). This statistic works out to around 125,000 fatigue-related injuries per day.

In the United States, about 23% of the population suffers significant sleep problems – the highest rate in the world (Uehli et al.). Reduced sleep and longer work hours are associated with greater injury risk – an approximate three-fold increase in the United States (Lombardi et al., 2010). Nighttime workers are almost three times more likely to be injured compared to daytime workers (Swaen et al., 2003). Jobs with overtime are associated with a 61% higher injury rate compared to jobs without overtime (Dembe et al., 2005). Working at least 12 hours per day is associated with a 37% higher injury rate and working more than 60 hours per week is linked to a 23% increase in injury rate (Dembe et al.). Finally, transportation data reveal 3,662 fatal crashes and 160,000 injury crashes involving fatigue-related drowsiness between 2011-2015 (NHTSA, 2017).

A review of scientific literature has shown that fatigue makes people perform worse, on average, than 90% of rested people on various tasks (Pilcher & Huffcutt, 1996). Sleep loss has been shown to decrease vigilance and impair reaction time capability (Krueger, 1989). Fatigue-related performance impairments on reaction-time, divided-attention, and memory-recall tasks can be similar to deficits that result from alcohol intoxication (Roehrs et al., 2003). These findings substantiate that fatigue impairs performance and poses injury risk.

Managing Fatigue

Fatigue management is challenging for several reasons. Perhaps the most straightforward is that fatigue is so common. Research suggests that significant chronic sleep loss exists in one-third or more of normal adults (Bonnet & Arand, 1995). Consistent with the idea that fatigue is common in the workplace, a National Safety Council (NSC) study surveyed over 2,000 American workers and identified several fatigue risks in the workplace (NSC, 2017). These risks included shiftwork, extended shifts and work weeks, long commutes, sleep loss, and lack of rest breaks.

The commonplaceness of fatigue is compounded by the fact that individuals struggle to accurately assess their own fatigue (Lerman et al., 2012). Yet another challenge in managing fatigue arises from the fact that fatigue and its causes can come from outside duty hours. Workers can show up to the facility already fatigued from dealing with long commutes, sleepless children, or any number of other fatigue hazards and risks. Managing fatigue is, therefore, a responsibility shared by individuals and companies. This variability only adds to that associated with workplaces that can vary substantially across industries, companies within those industries, business lines within those companies, and even facilities within those business lines. By extension, this workplace variability can entail different task demands and schedules. Unique facility and operational features can pose unique fatigue risks – an observation which supports the necessity of evaluating risks in a site-specific fashion.

Traditional Approaches

Individuals and companies alike have traditionally met their fatigue management responsibilities by relying on prescriptive approaches where limitations and requirements are imposed across organizational units (Gander et al., 2011). Two of the most common prescriptions are hour-of-service restrictions and minimum rest break requirements. These prescriptions are simple and can be helpful in limiting risk associated with some fatigue causes; however, they do not commonly or specifically limit worker exposure to fatigue risks associated with typical human sleep patterns, duty cycles, and non-work-related time such as that spent commuting. These factors are largely left to the individual to manage outside of the workplace setting, and this dichotomy – manage work fatigue, but come to work fatigued – poses significant challenges to risk management.

Fatigue Risk Management Systems

A progressive risk-based approach being adopted in several industries is the fatigue risk management system (FRMS). An FRMS is defined as a data-driven method for monitoring and managing fatigue-related safety risks through scientific principles and operational experience to help ensure personnel work with proper alertness (ICAO, 2011). Given that an FRMS is a management-system level administrative control, most comprehensive versions entail the following elements in one form or another:

- Introductory material conveying purpose, objectives, scope, and accountability;
- Policy statement of organizational commitment;
- Scientific definitions and information on sleep, fatigue, and fatigue countermeasures;
- Fatigue risk assessment and countermeasure processes, procedures, and guidance;
- Assurance and continuous improvement processes, procedures, and guidance;
- Fatigue awareness and training; and
- Implementation and communication plans.

Proliferation of the FRMS approach has resulted in several relevant guidance documents across multiple industries. While these documents collectively represent a significant step forward in industrial management of human fatigue, a common shortcoming in these documents is the lack of a practical and well-defined method for assessing risk and developing countermeasures. Process industries, for example, have recently produced at least two notable fatigue-focused guidance documents: *Assessing Risks from Operator Fatigue* (OGP, 2014) and *American Petroleum Institute (API) Recommended Practice (RP) 755, Fatigue Risk Management Systems of Personnel* (API, 2010).

The OGP guidance document recommends a two-stage fatigue risk management process by which facilities and operations are first screened and then analyzed for fatigue risks. This guidance document represents a significant step forward in fatigue management for the petrochemical industries. It highlights the importance of a risk-based approach and promotes assessment of fatigue at the level of worker activity. The OGP document has some limitations, however. It does not present guidance for developing and implementing a comprehensive FRMS. It also presents a method that would not only be relatively novel for most process safety professionals but would place significant responsibilities on those individuals for assessing specific fatigue-related task issues. Examples include defining action levels for fatigue and predicting levels of fatigue exposure using biomathematical models. These tasks can be quite challenging for safety professionals who are not reasonably expected to be well-versed in details of fatigue-related performance. This situation constrains the applicability and practicality of the approach.

Another limitation is that the recommended OGP processes do not offer opportunities to acknowledge any existing company, facility, or operational features that could be claimed as fatigue countermeasures. Such opportunities are important because using current features of a safety management system affords efficiency and promotes actual implementation of fatigue risk management. It may be much easier, and just as effective, to improve an existing countermeasure than to add a new one. For instance, a facility may already have a policy that limits overall overtime hours to control fatigue but does not limit contiguous overtime hours or overtime hours used to extend normal shifts. Adding these additional countermeasure modifications may be easier and more efficient for the company than implementing another countermeasure, such as adding staff to reduce overtime hours altogether.

Whereas the OGP document focuses more on assessing fatigue than managing it, API RP 755 does the opposite. In another welcomed step forward, the API document does offer guidance on several components that should be found in a comprehensive FRMS; however, it gives little functional guidance on actual fatigue risk assessment and control. A limited set of countermeasures are offered, but they are not connected to more specific features of fatigue that could reasonably be expected of a comprehensive risk-based approach. To help close these gaps, the rest of this paper focuses on a relatable, practical, and straightforward way to conduct a fatigue risk assessment (FRA).

A Practical Approach to Fatigue Risk Assessment

The FRA serves as the core of any FRMS because it consists of processes that enable the company to achieve its fatigue-related safety objectives. The FRA introduced here is conducted through a meeting of relevant stakeholders focused on fatigue and the human error that may result. The FRA is designed to (a) identify situations where fatigue may pose hazards, (b) assess the risks presented by those fatigue hazards, (c) note existing countermeasures, and (d) decide whether those countermeasures are adequate or whether additional fatigue countermeasures are required to sufficiently mitigate or control the relevant fatigue risk. These processes therefore offer a method for understanding the more specific ways human error can contribute to adverse incidents. Figure 1 schematizes the general process flow.

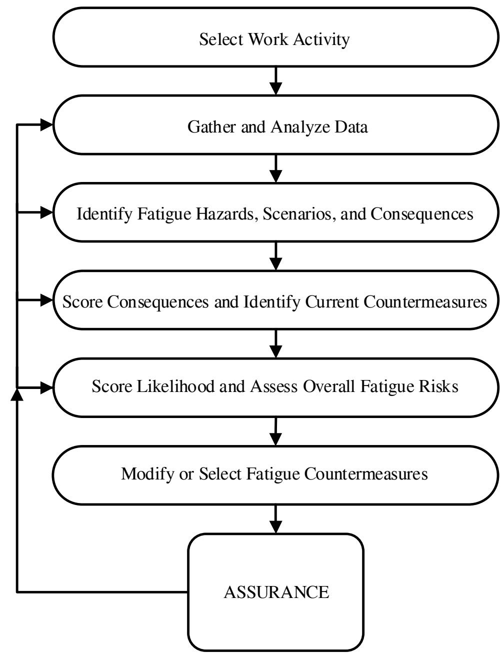

Figure 1. The Fatigue Risk Assessment Process Sequence

The first step is to identify the work activity where fatigue is thought to be a potential risk within the facility. This step should include a prioritization of work activities, and de facto, of the fatigue hazards found therein. This prioritization can be difficult, however, without previously having performed a risk assessment like the one pursued in this process. One way to deal with this issue is to rely on safety criticality of activities. The company can choose to ensure that all safety-critical work activities are subjected to, or at least carefully considered for, FRAs, or it can rely on a threshold of criticality to decide which tasks get FRAs and when.

An example work activity that could be selected in the first step of the FRA is starting a boiler. It is best to ensure that the activity is reasonably well defined. For instance, it would be helpful to decompose “starting the boiler” into procedural steps, such as (a) line up valves in startup position, (b) close bottom blowdown valves, and so on. Each procedure step can be subjected to an FRA. Note that it is not required to assess each procedure step – this option is just given for illustration.

The second step is to gather and analyze data. An objective of this step is to start understanding what fatigue hazards may exist in the work activity. Continuing with the boiler startup example, analysis may reveal that the boiler is routinely started during the early afternoon hours – a period of the circadian cycle known as a window of circadian low (WOCL) associated with increases in human error (Bjerner et al., 1955). One data source that should be considered entails results from previous safety studies or other types of risk assessments. Yet another is any analysis of factors that include fatigue hazards, or otherwise bear on fatigue; an example is overtime analysis often done for the sake of cost management that can also have implications for fatigue management. A final source includes recorded measurements of fatigue itself.

Fatigue measurement can be challenging. There is no single fatigue measure that can serve as a "gold standard," mainly because there can be many signs and symptoms of fatigue from multiple sources (ICAO, 2011). Two approaches can be used, however: (1) subjective measures, such as fatigue ratings based on memory or current perceptions and impressions, and (2) objective measures, such as performance tests and physical monitoring (ICAO, 2011).

When FRA processes are initially implemented, it is not always possible (or necessary) to gather new data. Over time, the assessments can be expected to mature as more data become available through additional collection and tracking requirements set forth in the larger FRMS. The following should be considered when deciding which measures to collect and analyze (ICAO, 2016):

- Fatigue-related impairment can affect multiple skills and can have multiple sources;
- Levels of effort should reasonably correspond to the level of fatigue risk, as assessed in the FRA;
- Balance should be maintained between gathering enough data and the additional demands that data collection and analysis can place on individuals;
- A set of measures can be chosen for routine fatigue monitoring; and
- Additional measures can be used if a unique fatigue hazard is identified and stakeholders decide that more information is needed.

The third step is to identify the fatigue hazards, scenarios, and consequences. A list of fatigue hazards can be developed or expanded based on the scientific literature, operational experience, and other data sources. The scenario is meant to be a written statement of how the particular work activity and fatigue hazard can lead to a potential consequence. For example, the fatigue hazard of starting the boiler during a WOCL could be associated with a scenario in which the operator forgets to open a vent valve leading to overpressure, catastrophic failure, and potentially multiple fatalities. It is important to note in the scenario to a reasonable degree of specificity the task in which the worker may make an error and the type of error considered.

Step four is to score the consequence severity of the incident using a company safety risk assessment matrix. The scenario to be assessed should be the worst-credible case, and incident severity scoring estimation should not consider existing countermeasures. Once the severity of a scenario is scored, any process or facility features that may function as fatigue countermeasures are identified. As mentioned, an example of an existing countermeasure is a policy that limits overtime hours to help control fatigue.

This is a good place to note that the FRA approach does not prohibit or preclude use of prescriptions. In fact, prescriptions such as hour-of-service limitations and mandatory break requirements can be helpful and should be claimed as countermeasures in the context of the FRA if present. This point notwithstanding, existing countermeasures should also be evaluated for appropriateness, specificity, and overall adequacy for the particular fatigue activity, hazard, risk, and scenario being evaluated.

General potential countermeasures from which the stakeholder team can select should be developed in the larger FRMS. An example of such a list for sleep loss includes considerations such as:

- Overtime;
- Long work hours and weeks;
- Commutes and travel;
- Health and wellness;
- Personal activities; and
- Company activities.

Step five is to score the likelihood of the scenario using the safety risk assessment matrix and assess the overall fatigue risk. The likelihood should consider existing countermeasures. The FRA should at all times be focused on hazards, risks, and countermeasures specific to fatigue.

Step six is to determine whether the overall fatigue risk is acceptable. This determination should entail discussion about whether current fatigue countermeasures are adequate. If the team determines they are not adequate, then new fatigue countermeasures should be issued, and action items should be assigned and tracked.

The final step in the FRA presented here is to develop fatigue-related performance indicators that allow assessment of how well those countermeasures perform in the future. Doing so should be a part of an assurance effort in which the company compares countermeasure performance with fatigue-related safety objectives established in the FRMS.

Recall that in our boiler-startup example we noted that modifications could be made to the facility overtime policy to help reduce fatigue risk. Fatigue-related performance indicators for those countermeasure modifications could be the proportion of (a) overtime versus non-overtime hours worked and (b) employees who have exceeded the maximum number of consecutive working days/hours before taking a rest day. Analyses of these types of indicators for countermeasure performance should be integrated in subsequent FRA reviews to facilitate continuous improvement.

CONCLUSION

This paper has covered adverse impacts of human fatigue and discussed some core challenges of managing associated safety risks. These challenges can dissuade safety and risk managers from incorporating fatigue in risk management, but the FRA provides a practical method that can be used to assess and control fatigue. The authors can confidently conclude that the methods are practical in large part because the methods have been implemented in practice. Partners and clients have met with substantial real-world success in applying the principles and guidance referred to above. Moreover, this success has spanned several lines of business, which was made possible because the approach promoted here is modular and flexible.

The most comprehensive approach to managing human fatigue described herein is the fatigue risk management system (FRMS). The FRMS is a modern method that relies on data, operational experience, and scientific principles of sleep and fatigue to identify current fatigue hazards and assess the risk associated with them (ICAO, 2011). As such, safety and risk managers can and should capitalize on existing safety management systems (SMSs) to grow a fatigue management program that benefits from other more common assurance and promotion processes.

A core element of the FRMS approach is the FRA. The FRA method leverages existing knowledge of safety professionals and administrative systems already in place within many industrial facilities, especially those in the process industries. One of the most critical conclusions is that the FRA can help fill gaps in relatively recently published fatigue guidelines for industry. The FRA method presented here is also flexible – while it is best-practice to conduct the FRA in the context of a larger FRMS, the method can be applied by itself using the steps outlined above. Regardless of the specific characteristics of the FRMS and FRA chosen, the risk-based approach is an effective way to manage workplace fatigue. Companies in several industries and across the globe are recognizing this utility and working to capitalize on it.

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