



INVITED PAPER

Managing Fatigue as an Integral Part of a Fatigue Risk Management System

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Professor Drew Dawson is currently the Director of the Centre for Sleep Research at the University of South Australia. He is nationally and internationally recognised for his contributions to the scientific community and to industry in the areas of organisational psychology and human factors, industrial relations negotiations, and the human implications of hours of work. He has worked extensively with the aviation, manufacturing, retail, entertainment, transportation, and mining sectors in Australia and is internationally recognised as a consultant on fatigue in the workplace. Drew has instigated fatigue management programmes, developed shiftwork and fatigue policy, undertaken pre-employment assessments, and facilitated shiftwork education sessions. Drew also regularly presents at national and international conferences and has provided expert witness testimony in several fatigue-related court cases.

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ABSTRACT

Fatigue has increasingly been viewed by society as a safety hazard. This has led to increased regulation of fatigue by governments. The most common control process has been compliance with prescriptive rule sets. Despite the frequent use of prescriptive rule sets, there is an emerging consensus that they are hazard control, based on poor scientific defensibility and lack of operational flexibility. In exploring potential alternatives, we propose a shift from prescriptive HOS limitations toward a broader safety management system approach. Rather than limiting HOS, this approach provides multiple layers of defence, whereby fatigue-related incidents are the final layer of many in an error trajectory.

This review presents a conceptual basis for managing the first two levels of an error trajectory for fatigue. The concept is based upon a prior sleep/wake model, which determines fatigue-risk thresholds by the amount of sleep individuals have acquired in the prior 24 and 48 hours. In doing so, managing level one of the error trajectory involves the implementation of systems that determine probabilistic sleep opportunity, such as prescriptive HOS rules or fatigue modeling. Managing level two, requires individuals to be responsible for monitoring their own prior sleep and wake to determine individual fitness for duty. Existing subjective, neurobehavioral and electrophysiological research is reviewed to make preliminary recommendations for sleep and wake thresholds. However, given the lack of task- and industry-specific data, any definitive conclusions will rely in post-implementation research to refine the thresholds.

KEYWORDS

Fatigue, prior sleep, wakefulness, safety, management, prescriptive rules, hours of service

GLOSSARY OF TERMS

<i>Fatigue</i>	for the purposes of this review all references to fatigue imply mental fatigue unless specifically indicated otherwise
<i>HOS</i>	Hours of Service
<i>OH&S</i>	Occupational Health and Safety
<i>SMS</i>	safety management system
<i>FRI</i>	fatigue-related incident
<i>FRE</i>	fatigue-related error
<i>PSWM</i>	prior sleep/wake model

BACKGROUND

Mental fatigue associated with working conditions has been identified as a major occupational health and safety risks in most developed nations. In part, this has been driven by scientific evidence, indicating an association between increasing fatigue and declines in cognitive function [1, 2], impaired performance [3, 4], increasing error rates [5, 6] and ultimately, reduced safety [7, 8]. Accordingly, governments and safety professionals have argued that mental fatigue is an identifiable work place hazard that warrants regulatory attention.

Traditionally, efforts in fatigue risk management have attempted to reduce fatigue-related risk through compliance with an agreed set of rules governing hours of work. In the U.S. these are generally referred to as hours of service (HOS) rule. At the most fundamental level, regulation has involved the prescription of maximum shift and minimum break durations for individual shifts or work periods. In addition, some industries and organizations have supplemented individual shift rules with supra-shift rules that further restrict the total number of sequential shifts or cumulative hours worked in a given period (e.g. week, month or year)[9, 10]. These limitations have typically been imposed coercively via a regulatory body or 'voluntarily' through a labor contract [11, 12].

The traditional prescriptive HOS approach most probably derives from earlier regulatory approaches for managing physical rather than mental fatigue. In the early part of the 20th century, OH&S hazards related to physical fatigue were managed primarily by regulating the duration of work and non-work periods. Previous research had indicated that physical fatigue accumulates and discharges in a broadly monotonic manner with respect to time [13]. As such, managing physical fatigue by limiting work hours and break periods was both scientifically defensible and operationally practical.

While the application of prescriptive duty limitations may have been an appropriate control for physical fatigue, we do not believe the same can be assumed for mental fatigue. It is common to use analogous approaches for the regulation of a new hazard. However, in the case of mental fatigue, this approach incorrectly assumes that the determinants of mental fatigue are similar to those for physical fatigue [14]. While it is true that mental fatigue does, in part, accumulate in a relatively linear manner [15], there are significant additional non-linearities driving the dynamics of fatigue and recovery processes for mental fatigue.

Circadian biology, for example, influences the dynamics of fatigue accumulation and recovery in a way that produces significant non-linearities [16]. For example, prescriptive limitations on shift duration generally assume that a break of a given length has a uniform recovery value with respect to mental fatigue. While this may be relatively true with respect to physical fatigue, it is demonstrably not the case with respect to mental fatigue. Indeed, providing the same length of time off during the subjective day, as opposed to subjective night, will result in a significantly reduced amount of recovery sleep [17].

In our opinion, estimating the level of mental fatigue associated with a given pattern of work is linked more to the timing and duration of sleep and wake within the break, rather than the duration of the break alone. Although there is clear scientific evidence to support this notion, few regulatory models acknowledge it explicitly. As depicted in figure 1, it is our view that regulatory models based only on shift duration are unlikely to produce congruence between what is safe and what is permitted and what is unsafe and not permitted.

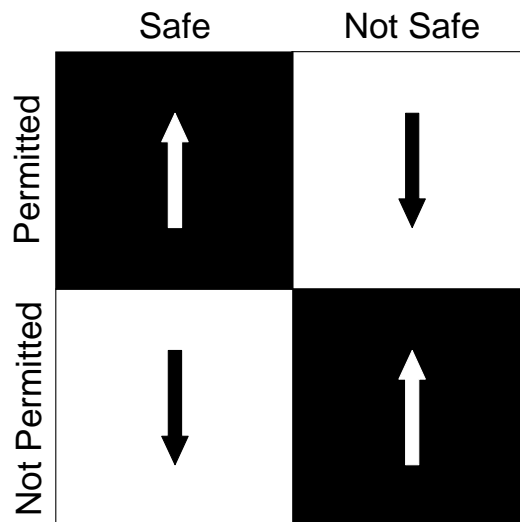


Figure 1. Effective regulatory models should provide congruence between what is safe, and permitted as well as what is unsafe, and not permitted. This is often not the reality with traditional prescriptive HOS regulatory approaches.

The relationship between the recovery value of non-work periods (vis-à-vis mental fatigue) and the actual amount of sleep obtained has become increasingly complex in recent years. In addition to the biological limitations of this approach, increases in total working hours, lengthening of shift durations from eight to twelve hours, and concomitant reductions in breaks from sixteen to twelve hours [18] have significantly restricted the opportunity for sleep. Furthermore, changes in workforce demographics and the social use of time in and outside the workplace have exerted additional downward pressure on the amount of time individuals choose to allocate for sleep [19].

RECENT TRENDS IN FATIGUE MANAGEMENT

As outlined above, many of the current approaches to fatigue management have focussed on hours-of-service. However, these approaches may be of limited value in the systematic management of fatigue-related risk. This has been particularly highlighted by recent research and policy initiatives in the US [11] Australia [20-22], Canada [23] and New Zealand [24, 25]. In these jurisdictions, there is an emerging, albeit controversial, view that we might more usefully explore alternatives to prescriptive models of fatigue management. Moreover, relative to traditional prescriptive approaches, alternative approaches may hold significant potential for improved safety and greater operational flexibility.

To date, most alternative approaches to prescriptive HOS embed fatigue management within the general context of a Safety Management System (SMS) and arguably provide a more defensible conceptual and scientific basis for managing fatigue-related risk as well as the potential for greater operational flexibility [26, 27]. This is in marked contrast to current HOS models whose roots are inextricably bound up in the history of their labor relations process where the primacy of short-term financial factors has frequently distorted safety outcomes [28, 29].

Despite the theoretical attraction of alternative approaches to prescriptive HOS, many commentators have, with good reason, expressed reservations about their actual benefits in practice. For example, an increase in the flexibility of HOS regulation has often been interpreted (by employees and their representatives) as a disingenuous attempt to deregulate or subvert current or proposed HOS rules. Conversely, tightening of HOS regulation to reduce fatigue has sometimes been interpreted (by employer groups and their advocates) as a disingenuous attempt to leverage better pay and conditions, rather than improve safety [27].

For the last few years, our research group has conducted extensive consultation with industry stakeholders and regulators in several countries and in a variety of industries, to understand how fatigue might best be managed using alternative approaches. In doing so, we have canvassed two broad approaches. First, the modification of traditional prescriptive HOS regulations to ensure they address matters related to legal and scientific defensibility as well as operational flexibility. Second, we have considered alternative regulatory models that might be used as the basis of a new approach that meets the previously mentioned goals of scientific defensibility and flexibility. Our objective was to establish a well-structured view of how fatigue might best be regulated, as well as the most appropriate way in which such reform might be achieved at the practical level.

On the basis of discussions with industry, we believe there is an emerging consensual view that:

- Given the diversity of modern organizational practice, a traditional prescriptive HOS approach may not be the most appropriate or only way to manage fatigue-related risk;
- Alternative approaches to prescriptive HOS for fatigue management have significant potential to improve operational flexibility and safety;
- Alternative approaches also hold significant potential to be abused by organizations or individuals for whom regulatory enforcement is a low probability event and/or the consequences of non-compliance are trivial;
- Alternative approaches will require a significant maturation in organizational and regulatory culture if they are to be successful in reducing fatigue-related risks to the community; and
- There should be a standard methodology of measuring outcomes and program efficacy.

AN ALTERNATIVE APPROACH TO PRESCRIPTIVE REGULATIONS

On the basis of discussions with key industry and regulatory stakeholders, it is our view that the most appropriate solution for effective fatigue management, is to expand the regulatory framework from a prescriptive HOS approach and to permit certain organizations to use a Safety Management Systems (SMS) approach. This would be based on existing occupational safety and health standards, practices and principles (e.g. Canadian OH&S act; the OHSAS 18001; the Australian/New Zealand standard for occupational health and safety management systems AS/NZS 4801:2001) [30-32]. From this perspective, fatigue would be managed as an 'identifiable OH&S hazard' and would be one part of a more general organizational SMS.

It may also be useful to expand our use of a prescription/compliance perspective to include approaches that emphasize outcomes. That is, rather than prescribing one universal rule set, the management of safety risks could be effectively achieved in a variety of organization- or industry-specific ways. In doing so, it would be the responsibility of each organization or industry to develop a fatigue risk management 'code-of-practice, and through formal review processes, continue to refine and improve the safety environment vis-à-vis fatigue. According to this view, the role of regulation would be to legislate for an outcome (e.g. a reduction in fatigue-related risk) rather than assume that compliance with a prescriptive HOS standard implies, and ensures, a given level of safety.

To date, most examples of outcome-based systems for fatigue risk management have been developed within the transportation sector. These include the Transitional Fatigue Management Program, developed by Queensland Transport [33]; the Australian Civil Aviation Safety Authority (CASA) Fatigue Risk Management System [22-27]; Fatigue Risk Management Programs of a number of Australian rail organizations [21]; and the North American Federal Railroad Administration [11]. In addition, air traffic controllers in both Australia and New Zealand have used hybrid prescription/outcome-based approaches for several years [24].

Initial pilot studies or projects using outcome-based fatigue risk management have had mixed results with early evaluations suggesting the approach has considerable potential but significant risks associated with poor enforcement and assessment [27]. Furthermore, there has been minimal work assessing their longer-term efficacy or enforceability. Until such projects mature and evaluative research is published, the scientific safety community should continue to develop and refine the conceptual framework that underlies such systems.

Traditionally, and particularly within Europe, it has been common for policy makers (often in conjunction with relevant researchers) to develop recommendations on what are considered acceptable shifts and/or patterns of work. For example, forward rotating shifts [34]; maximum number of sequential working days [35]; length of shift (8, 10 or 12 hours) [36, 37]; and minimum number of days off required for recovery [16]. These, in turn, have been published and subsequently held up as *de facto* standard. Using these standards, shifts are constructed as either stable roster patterns, or flexible rosters that are constructed from pre approved scheduling features (e.g. no more than four night shifts in a row, or no break less than eight hours). Using this approach, a roster or schedule is deemed acceptable if it does not contain any unapproved features.

The advantage of this approach is that it treats the roster as an integrated whole. The disadvantage is that it makes it difficult to generalize to novel or innovative rosters or schedules. Furthermore, it fails to identify individual differences in fatigue-related risk. This approach assumes, at least implicitly, that the effects of a given shift system are similar for all individuals. That is, it fails to address potential interactions between the shift system and employee demographics. A final criticism is that it fails to distinguish between work-related causes of fatigue and fatigue due to non-work related causes. That is, it is possible for an individual to arrive at work fatigued due to inappropriate use of an adequate recovery period.

To gain the generalisability and flexibility of a feature-based approach, without the disadvantages of inadvertent interaction between features, we would propose a novel methodology for defining the degree of fatigue likely to be associated with a particular roster or schedule. Before we address that approach in detail, it is essential to place the discussion in context. It is particularly important to understand the way we have traditionally approached fatigue management. Notably, that it has been addressed primarily as a labor relations, rather than safety management, issue.

DEVELOPING A CONCEPTUAL FRAMEWORK FOR FATIGUE MANAGEMENT

Most regulatory frameworks to date have not considered fatigue as a hazard to be managed as part of Safety Management System. Instead, fatigue has been managed through compliance with a set of externally imposed prescriptive rules. While this is understandable, there is no reason, other than historical bias, that precludes the use of the same SMS principles that would apply for any other identifiable safety hazard.

Furthermore, we would suggest that this framework provides a sounder conceptual basis for managing fatigue-related risk fatigue management. In addition, it could easily sit within the pre-existing and emerging Safety Management System [SMS] frameworks currently advocated by regulators and safety professionals.

This methodology can be represented using Reason's (1997) [38] hazard control framework. A fatigue-related accident or incident [FRI] is seen as only the final point of a longer causal chain of events or 'error trajectory'. An examination of the error trajectory associated with a FRI will indicate that there are four levels of antecedent event common to any FRI.

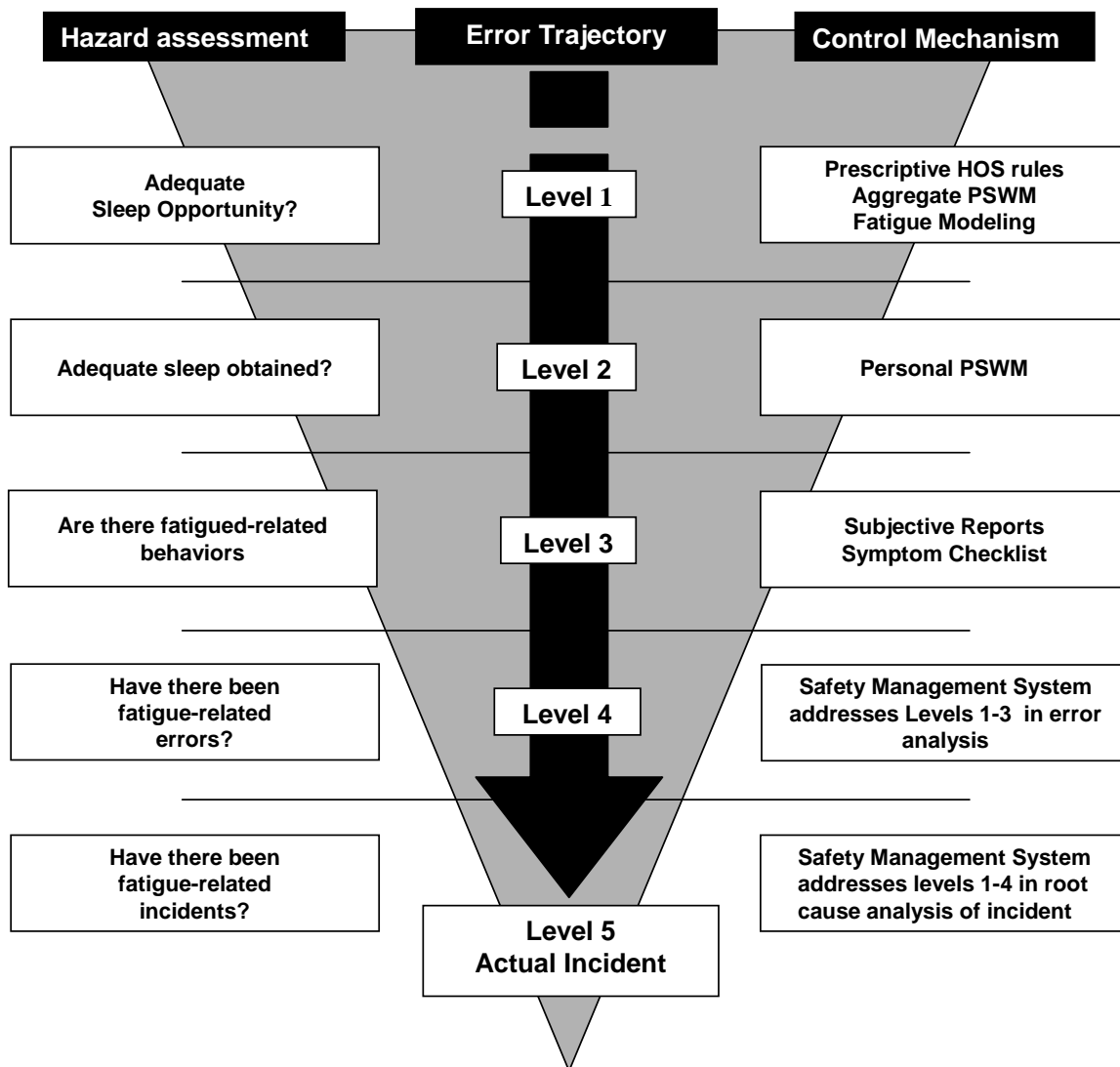


Figure 2. Fatigue risk trajectory. There are multiple layers that precede a fatigue-related incident, for which there are identifiable hazards and controls. An effective fatigue risk management system should attempt to manage each layer of risk.

From figure 2, a FRI is merely the end point of a causal chain of events or 'error trajectory' and is always preceded by a common sequence of event classifications that lead to the actual incident. Thus, a FRI is always preceded by a fatigue-related error [FRE]. Each FRE, in turn, will be associated with an individual in a fatigued state, exhibiting fatigue-related symptomology or behaviors. The fatigued state in the individual will, in turn, be preceded by insufficient recovery sleep or excessive wakefulness. Insufficient sleep or excessive wakefulness will be caused by either (a) insufficient recovery sleep during an adequate break (e.g. fail to obtain sufficient sleep for reasons beyond their control, choosing to engage in non-sleep activities or a sleep disorder) or (b) by an inadequate break. (e.g. the roster or schedule did not provide an adequate opportunity for sufficient sleep).

Each of the four steps in the general error trajectory for a FRI provides the opportunity to identify potential incidents and, more importantly the presence (or absence) of appropriate control mechanisms in the system. It is also often the case that many more potential incidents (i.e. "near misses") will occur than actual incidents and that these could, if monitored, provide a significant opportunity to identify fatigue-related risk and to modify organizational process prior to an actual FRI.

Potentially, this framework would enable us to identify the root causes of many potential FRI's in a logical and consistent manner. In addition, we can systematically organize and implement effective hazard control measures for fatigue-related risk at each 'level' of control using a systems-based approach. The figure also implies that we can reduce the incidence of fatigue-related incidents by more co-ordinated or integrated control of the antecedent events or behaviors that constitute potential or 'latent' failures of the safety system [38].

Effective management of fatigue-related risk requires a fatigue risk management system (FRMS) that implements task and organizationally appropriate control mechanisms for each point in the theoretical error trajectory. Where an organization fails to develop appropriate controls at each level of the hierarchy, it is unlikely that, overall, the system will be well-defended against fatigue-related incidents.

The figure also provides a useful way of understanding (1) the piecemeal and uncoordinated nature of many regulatory approaches to fatigue management to date; and (2) why unintegrated approaches to managing fatigue related risk (such as sole use of prescriptive HOS rules) may not be entirely successful.

In general, accident investigations have focused primarily on later segments of the error trajectory when trying to identify whether fatigue was a contributing factor. Conversely, when framing regulatory responses to fatigue-related incidents (as a control measure), there have rarely been systematic attempts to address all levels and few, if any, directed to lower levels of the error trajectory. In doing so, policy makers have assumed that compliance with prescriptive HOS rule sets and other relevant labor agreements, constitutes an effective control measure for fatigue-related risk. As such, even if individual organizations were to achieve explicit compliance (admittedly a farcical assumption in many industries), they implicitly (and erroneously) assume that:

- A rule set can determine reliably whether an individual will be fatigued (or not); and
- Individual employees always use an ostensibly adequate opportunity for sleep appropriately and obtain sufficient sleep.

Since, in many situations, these two assumptions are demonstrably untrue, an effective FRMS must provide additional levels of controls for those occasions when the preceding levels of control prove might ineffective.

As can be seen from recent alternative, systems-approach initiatives, there can be very different intellectual and emotional perspectives on the appropriateness and relative merits of different control mechanisms at a single level of the diagram. For example, in recent years there has been considerable discussion as to the relative merits of fatigue-modelling [39] and the more traditional HOS approaches [34,37]. From the perspective in figure 2, both are only level 1 control strategies that attempt to ensure that employees are given, on average, an adequate opportunity to gain sufficient sleep. Since this is only a probabilistic determination and no hazard control mechanism is perfect, neither will prevent all error trajectories in figure 2 projecting beyond level 1. Thus a system with little or no hazard controls at level 2 or beyond may be quite poorly defended against FREs. Similarly, in a system that has very effective hazard control strategies at levels 2-4, debates about the relative merits of different level 1 strategies could arguably be considered moot.

The following sections of this paper will focus on describing a novel conceptual basis for the development of appropriate control mechanisms for fatigue-related hazards and the scientific justification for such an approach.

As can be seen from figure 2, an effective approach to fatigue management will require a variety of control measures applied at each of the four points on the error trajectory. Thus, an effective FRMS would require control procedures at level 1 of the error trajectory that ensure employees are provided with an adequate opportunity for sleep. It would also require control procedures at level 2 that ensure that employees who are given an adequate opportunity for sleep actually obtain it. At level 3 we need to ensure that employees who obtained what is considered, on average, sufficient sleep are not experiencing actual fatigue-related behaviors (e.g. due to sleep disorders, non-work demands or individual differences in sleep need). The use of symptom checklists or subjective fatigue scales is an example of control procedures at this level. Similarly, we would need control procedures at level 4 to identify the occurrence of FRE that did not lead to a FRI. Finally, an effective FRMS would require an incident analysis and investigation procedure to identify those occasions when all the control mechanisms failed to prevent an FRI.

The development of appropriate control procedures at level 3 and above is beyond the scope of this paper. These will be addressed in subsequent publications. In this review, we will focus on levels 1 and 2. In particular, we will propose a novel conceptual framework for the design, and implementation of control procedures at levels 1 and 2 of the error trajectory outlined in figure 2. That is, control methods for determining whether:

- a roster or schedule provides, on average, an adequate opportunity to obtain sufficient sleep and
- if so, whether an individual has actually obtained sufficient sleep

EXISTING EFFORTS OF HIGHER-ORDER FATIGUE RISK MANAGEMENT

Historically, the principal level 1 control mechanism has been the development of prescriptive HOS rule systems that purport to provide adequate opportunity for sleep. In recent years there has been an emerging scientific and regulatory consensus that many of our prescriptive shift work rules do not provide a reliable control mechanism that prevents fatigued individuals from unsafe working practices [11, 40]. This is due primarily to a failure to distinguish between:

- non-work and sleep time in determining the recovery value of time-off; and
- the failure to take into account the time-of-day at which shifts or breaks occur [41].

As a consequence, there has been a strong move toward developing different approaches to ensuring an adequate average opportunity to obtain sleep for fatigue risk management. Broadly speaking these can be divided into two groups:

- modified prescription; and
- fatigue modelling

From a practical perspective, it is important to determine whether a given shift system, on average, enables an individual to report fit-for-duty. That is, whether the particular pattern of work provides adequate opportunity for sleep. Recently, fatigue modeling has provided an appealing alternative to traditional prescriptive approaches in that it appears more 'scientific' and it provides a reliable method to determine whether a pattern of work adequately limits waking time and provides adequate opportunity for sleep. For a comprehensive review of existing models, see the 2004 issue of *Aviation, Space, and Environmental Medicine* [42].

While some of the models are extremely useful for predicting average levels of fatigue at the organizational level, they are not particularly useful for determining whether a given individual is fit-for-duty on a given occasion. Specifically, such approaches are unlikely to provide conclusive indications of whether an accident or incident was due to fatigue, because they can tell us nothing about individual behavior on a given day. Thus, while modeling approaches to fatigue risk management represent a significant potential improvement in our capacity to assess general aspects of a schedule, they do not provide controls any higher than level 1 in the error trajectory. Most importantly, they provide little or no guidance for determining the likelihood of fatigue, and therefore fatigue-related risk on a day-to-day basis for individuals within the organization.

There have been some attempts to develop control mechanisms for fatigue at higher levels in the 'error trajectory'. For example, in some regulatory environments individuals have been assigned the right and/or responsibility to override prescriptive guidelines where they believe it is appropriate (e.g. Civil Aviation Order 48 [10]). The difficulty with this requirement is the reliability of self-assessment of fatigue. That is, although people can estimate their level of fatigue or alertness with some degree of reliability, we have very little scientific evidence to support the notion that individuals can use this information to make reliable subjective judgements about the concomitant level of risk or safety and relative fitness-for-duty. It also ignores the very real potential for coercive financial, social and operational pressures to distort effective decision making in this area.

In other jurisdictions, we have seen enthusiastic attempts to introduce the requirement to train and educate employees about fatigue. These initiatives, while well intentioned, assume that training and education in itself will produce beneficial changes in individual and organizational safety behavior with respect to fatigue-related risk.

Despite significant spending in this area, to date, there is little or no published evidence to support the hypothesis that improved knowledge of the determinants of fatigue and potential countermeasures leads to improved hazard control [43].

Given the shortcomings of fatigue modeling and subjective self-estimations of fatigue, we propose a behaviorally-based methodology for assessing fatigue. The model proposed in the remainder of this paper outlines methods for predicting average levels of fatigue at the organizational level, as well as control mechanisms for the more specific, day-to-day risk of fatigue at the individual level within organizations.

PRIOR SLEEP AND WAKE AS THE BASIS FOR A GENERALIZED APPROACH TO ASSESSING FATIGUE

The first point we would make is that we do not yet have a detailed understanding of the relationship between increasing fatigue and risk for many industries and occupations. There is a significant body of laboratory research indicating that increasing fatigue is associated with increases in the probability and/or frequency of certain types of performance degradation on standard measures of neurobehavioral performance [3, 4, 44-46]. However, the best that can be said with particular regard to safety is that increasing fatigue is typically thought to be associated with increasing likelihood of error [5, 47]. Thus, we are not yet at a point where research can be used to clearly articulate the likelihood or typology of errors for specific tasks and/or workplace settings.

At best, we can suggest that based on the published literature:

- Error rates increase exponentially with linear increases in psychometric measures of fatigue [4];
- Errors are broadly comparable in nature and frequency with other forms of impairment (e.g. alcohol intoxication) [48, 49]; and
- We can make only general predications about the susceptibility of certain types of tasks to fatigue-related error.

In view of our lack of a detailed understanding of workplace or task specific risk associated with fatigue, any set of guidelines should be considered provisional, tentative and subject to ongoing refinement on the basis of post-implementation evaluation.

With this caveat in mind, we would suggest that knowledge of the frequency distribution of prior sleep and wake could form a rational basis for determining the level of fatigue an individual is likely to experience within a given shift. Furthermore, there is potential for both individuals and organizations to use this information as the basis for rational decision making with respect to fatigue-related risk. Within this framework, there are two main questions that should be asked. First, is the individual fit-for-duty and acceptably rested to commence work? The second question is predicated on the answer to the first. That is, if an individual is acceptably alert to commence work, for what period of time can they be reasonably expected to work before fatigue subsequently creates an unacceptable level of risk?

As a starting point for this decision, we suggest that a rational FRMS should be based on prior sleep and wake rules, linked to an evaluation of the adequacy of prior sleep and wake. The reasons for this are straightforward:

- Unlike subjective estimates of fatigue, prior sleep and wake are observable and potentially verifiable determinants of fatigue;
- Prior sleep and wake provide a way of integrating individual and organizational measures of fatigue (levels 1 and 2) since systems-based approaches can deal with probabilistic estimates of sleep and wakefulness, and individual employees can make clear determinations of individual amounts of actual prior sleep and wakefulness; and
- Prior sleep and wake measures can be set or modified according to the risk profile associated with specific tasks or workgroups.

In order to determine whether an employee is likely to be fatigued and the required degree of hazard control, we propose a simple algorithm based on the amount of sleep and wake experienced in the 48 hours period prior to commencing work.

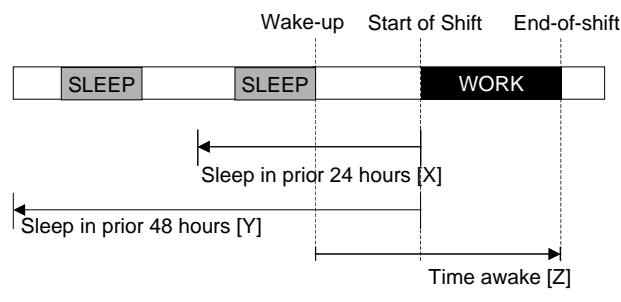


Figure 3. Prior Sleep Wake Model (PSWM). Fitness for work at levels 1 and 2 of effective fatigue risk management can be determined by an algorithm that is comprised of three simple calculations: prior sleep in the last 24- and 48-hours; and length of wakefulness from awakening to end of work.

As can be seen above in figure 3, the algorithm is comprised of three simple calculations. That is:

Prior Sleep Threshold – Prior to commencing work, an employee should determine whether they have obtained:

- a) X hrs sleep in the prior 24 hours; and
- b) Y hrs sleep in the prior 48 hours.

Prior Wake Threshold – Prior to commencing work an employee should determine whether the period from wake-up to the end of shift exceeds the amount of sleep obtained in the 48 hours prior to commencing the shift.

Hazard Control Principle – Where obtained sleep or wake does not meet the criteria above, then there is significant increase in the likelihood of a fatigue-related error and the organization should implement appropriate hazard control procedures for the individual.

A critical aspect of the rules defined above is to create appropriate threshold values for the minimum sleep values for the prior 24 and 48 hours to commencing work and the amount of wakefulness that would be considered acceptable. It is important to note that the thresholds could potentially vary as a function of fatigue-related risk within a workplace. For example, if a given task has either a greater susceptibility of fatigue-related error, or there are significantly greater consequences of a fatigue-related error, the threshold values may be adjusted to a more conservative level.

From this perspective, fatigue related accidents or incidents are seen as the final segment in a causal chain of events or error trajectory. Within the error trajectory there are four identifiable segments common to all fatigue-related incidents. At the earliest levels of the error trajectory are segments related to (1) the provision of an adequate opportunity to sleep and (2) appropriate utilization of a sleep opportunity [break period]. In this review we have proposed a novel methodology that enables organizations to take an integrated approach to determining whether they have appropriate control procedures at level 1 or 2 of the proposed fatigue-related error trajectory.

The basis to this methodology is the prior sleep wake model (PSWM). The conceptual basis to this model is that fatigue is better estimated from prior sleep/wake behavior than from patterns of work. Using this model, an organization can define task specific thresholds for sleep and wakefulness based on the amount of sleep obtained in the 24 and 48 hours prior to commencing work. Where aggregate or individual sleep/wake values fail

to reach pre-designated thresholds, the increased likelihood of fatigue would require a greater level of hazard control to prevent an actual incident from occurring (levels 3 and 4).

At level 1 of the error trajectory organizations are required to manage the opportunity for sleep probabilistically. In general, prescriptive rule sets or fatigue modeling are the most common ways in which an organization can determine prospectively whether a pattern of work is likely to provide employees with an adequate opportunity to obtain sufficient sleep (vis-à-vis the defined threshold). Using this approach, an acceptable roster or schedule is one that is associated with a certain percentage of people on average (e.g. > 95%) having an adequate opportunity to gain the requisite amount of sleep.

At level 2 of the error trajectory, individuals use the PSWM to determine whether they have had sufficient sleep. Since level 1 control mechanisms will allow a pre-determined percentage of employees insufficient sleep (e.g. 5%) the personal PSW calculation will allow them to identify themselves, report this information and the organization can engage in appropriate control procedures at level 3 and above in the error trajectory.

In determining appropriate threshold values for sufficient sleep this review acknowledges that currently, there is a dearth of organization- and/or task-specific data sufficient to answer this question definitively. Indeed it is our view that such data will be collected by organizations in the post-implementation phase.

In defining this threshold we caution readers that particular occupational tasks may well be more susceptible to fatigue-related error or the consequences of fatigue-related error are so severe as to require threshold values greater than we have specified. Furthermore, any initial values should be viewed as a starting point and subject to revision in the light of actual workplace experience. However, where thresholds are inappropriate, we should see the systematic projection of error trajectories beyond level 2. That is, despite achieving the requisite threshold levels of sleep the FRMS would continue to observe either

- level 3 factors indicating the occurrence of fatigue-related behaviors or symptoms;
- level 4 factors related to the occurrence of fatigue-related errors; or
- level 5 issues related to the occurrence of actual fatigue-related incidents.

Level 3 of the error trajectory is characterized by the presence of fatigue-related behaviors. There will inherently be individual differences in the experience of fatigue as a direct consequence of sleep. That is, even if an individual complies with the organization's minimum sleep thresholds (as set out in levels 1 and 2), it is possible, due to specific work environment or life circumstances, that they may still experience fatigue symptomology. Thus, the observance of fatigue-related behaviors acts as an additional layer of defense, to avoid fatigue-related errors or accidents. The types of controls we would envisage at this level would include subjective reports of fatigue from individuals to managers, or the presence of symptoms from a 'fatigue symptom checklist', which would be provided to employees by the organization.

While levels 1-3 of the error trajectory take a proactive approach to fatigue risk management, levels 4 and 5 take a more reactive approach. They are more concerned with investigative procedures when failures have occurred at the earlier levels of the error trajectory. Level 4 is defined by the occurrence of a fatigue-related error. Such an error may not necessarily lead to an actual accident or incident. However, if it is detected, an investigation should be conducted to determine the cause of the error, and prevent similar occurrences from happening again. Specifically, the investigation should focus on levels 1-3 to determine deficiencies in the control processes. This would be performed as a part of the safety management system error analysis framework.

Level 5 is the final level in the error trajectory, whereby a fatigue-related error results in an incident or accident. In reality, it is unlikely that such an event would be solely caused by fatigue, and could be linked to several different causal factors. However, to determine the extent to which fatigue was specifically involved, the investigation should focus on levels 1-4 of the error trajectory to determine deficiencies in the control processes. This would be performed as a part of the safety management system accident/incident investigation framework.

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