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Fatigue risk management: Organizational factors at the regulatory and industry/company level

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ABSTRACT

This paper focuses on the development of fatigue risk management systems (FRMS) in the transport sector. The evolution of regulatory frameworks is traced, from uni-dimensional hours of service regulations through to frameworks that enable multi-dimensional FRMS. These regulatory changes reflect advances in understanding of human error in the aetiology of accidents, and in fatigue and safety science. Implementation of FRMS shifts the locus of responsibility for safety away from the regulator towards companies and individuals, and requires changes in traditional roles. Organizational, ethnic, and national culture need to be considered. Recent trends in the work environment have potential to adversely affect FRMS, including precarious employment and shortages of skilled labour. Essential components of an FRMS, and examples of FRMS in different transport modes, are described. It is vital that regulators, employer, and employees have an understanding of the causes and consequences of fatigue that is sufficient for them to meet their responsibilities in relation to FRMS. While there is a strong evidence base supporting the principles of FRMS, experience with implementation is more limited. The evidence base for effective implementation will expand, since FRMS is data-driven, and ongoing evaluation is integral. We strongly advocate that experience be shared wherever possible.

1. Introduction

1.1. Scope

This paper considers work-related fatigue and strategies to minimize the safety hazard that it represents, particularly in the transport sector. Responsibility for fatigue risk management can be identified at three levels: (1) regulatory responsibility; (2) industry/company responsibility; and (3) individual responsibility.

Regulatory and enforcement regimes at the state, national, and international level (for aviation and maritime operations) aim to limit public exposure to the risks associated with fatigued transport operators. They define organizational parameters that must be included in a company's approach to fatigue risk management. The paper examines the evolution of regulatory approaches and how they are affected by the broader occupational health and safety legislation with which they co-exist.

At the operational level, fatigue risk management is a shared responsibility of employers and employees. This is unavoidable because fatigue differs from many other workplace hazards (such as exposures to toxic substances, dust, noise, etc.) in that it is affected by all waking activities, not only those that are work-related (see definitions below). The present paper focuses on industry and company organizational factors, while another paper in this special issue considers individual factors relevant to fatigue risk management in more detail (see Di Milia et al., 2011).

A wide range of organizational factors have been identified that can impact on fatigue in transportation, negatively or positively (Arnold, 1999; Arnold and Hartley, 2001) including:

- the cultural, regulatory and enforcement environments;
- the size of the company;

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- the nature of the business (who/what is transported, where and when);
- the level of commitment to health and safety (the safety culture) in the company;
- the presence of safety management systems (SMS), including systems for non-punitive reporting of safety concerns;
- the nature and extent of supervision (in transport operations employees are typically mobile and can be out of contact with direct supervision for long periods of time);
- remuneration practices (payment by the trip, by the hour, overtime rates, etc.);
- knowledge about fatigue among staff at all levels in the organization; and
- for individual employees, their perceived quality of working and domestic life.

An exhaustive discussion of all operational factors affecting fatigue risk management in the globalized transport system is beyond the scope of this paper. Instead, it draws on the theoretical understanding and practical experience of the authors, which encompasses a range of jurisdictions and transport modalities. The review of regulatory regimes is intended to be illustrative rather than complete, covering regimes about which the authors have particular knowledge. The aims of the paper are to examine current knowledge and practise in regard to organizational factors in fatigue risk management, to identify where there are significant gaps, and to consider the way forward.

1.2. Definitions

Managing the health and safety risk associated with fatigue in a workplace requires a clear definition of fatigue. The following operational definition is taken as the basis for this paper.

> Fatigue is the inability to function at the desired level due to incomplete recovery from the demands of prior work and other waking activities. Acute fatigue can occur when there is inadequate time to rest and recover from a work period. Cumulative (chronic) fatigue occurs when there is insufficient recovery from acute fatigue over time. Recovery from fatigue, i.e., restoration of function (particularly of cognitive function), requires sufficient good quality sleep.

Performance capacity is systematically affected by a range of factors that need to be considered in a comprehensive approach to fatigue risk management.

- It fluctuates across the daily cycle of the circadian biological clock, so the risk of fatigue is greater when performance capacity is reduced during biological night.
- It is reduced in a cumulative, dose-dependent manner by restricted sleep.
- It decreases as continuous time awake increases.
- It decreases as continuous time on a task increases, and the rate of decline is influenced by the intensity of work demands (workload).

The effects of fatigue can be measured as changes in brain function, behaviour, or subjective experience.

Fatigue risk management is here defined as the planning and control of the working environment, in order to minimise, as far as is reasonably practicable, the adverse effects of fatigue on workforce alertness and performance, in a manner appropriate to the level of risk exposure and the nature of the operation.

Comprehensive fatigue risk management includes both strategies to reduce the likelihood of people being fatigued at work (*fatigue reduction*, for example better shift work schedules) and strategies to mitigate the risk represented by a fatigue-impaired individual in the workplace (*fatigue proofing*).

2. Regulatory approaches

Regulatory approaches for fatigue risk management are evolving. Traditional hours of service (HoS) regulations sought to reduce fatigue risk by limiting maximum work hours and minimum rest breaks. Increasingly, regulatory frameworks are being developed that permit an alternative to this uni-dimensional approach (Dawson and McCulloch, 2005), namely multi-dimensional fatigue risk management systems (FRMS). The following sections illustrate some of the changes that have occurred in regulatory frameworks, and examine how management of fatigue risk relates to the management of workplace hazards in general, in broader occupational health and safety legislation.

2.1. Historical context of working hours limits and occupational health and safety legislation

Historically, regulatory limits on hours of work evolved in a broader industrial relations context, aiming to balance working conditions and remuneration. In the United Kingdom, the industrial revolution increased the focus on limiting hours of work, particularly in the textile industry. From the late 18th century onwards, various movements grew up advocating limits, with the aims of maintaining quality of life (e.g., "8 h work, 8 h recreation, 8 h rest") and protecting women and children in particular. The Factories Act (1802) was the first government regulation limiting working hours in the UK, but little effort was invested in workplace inspections or enforcement. However, it paved the way for the better known Factory Act of 1833, which restricted the duration and timing of work, especially for children, and provided for lunch breaks and for workplace inspections in the textile industry to enforce its provisions (Cornish and Clark, 1989).

These movements had parallels in other countries including the USA, Australia, New Zealand, France, and Germany, and they laid the groundwork for the development of regulations to limit working hours across a range of industries. The regulations tried to balance productivity, investment return, wages, quality of life, and safety, with the minimal scientific evidence available to inform the choice of safe limits. Not surprisingly, limits were frequently revised.

In 1970, the first comprehensive US Federal occupational safety and health (OSH) legislation was enacted. In other countries, the 1970s saw a significant shift away from the traditional focus on prescriptive limits on working hours, towards a more general duty of care for managing workplace safety and health in a more integrated manner, while separating it from considerations of remuneration. In the UK, the influential Robens Report (1972) laid out the principles for the Health and Safety at Work Act (1974). Robens argued that the Factory Acts and Regulations were too numerous, elaborate and overly focused on the physical circumstances of work, rather than on workers and safe systems of work. He proposed legislation confined to broad statements setting goals for safety and dealing with environmental standards, particular hazards and particular industries.

Important progress was being made at this time in understanding the complexity of risk, as a result of the development of high risk industries such as the nuclear industry. On the one hand, many different models of risk were being proposed, each emphasising different perspectives and having different implications for risk management. On the other hand, advances in understanding of the causes of different types of risk brought rapid progress in managing risk, as has been the case with fatigue-related risk in the last 20 years. These two trends have been instrumental over the last 50 years in shifting risk management away from simple uni-dimensional prescription to multi-faceted risk management. Of particular importance was the work of Mary Douglas, which emphasised the socio-political context of risk and its perception (Douglas and Wildavsky, 1982). The key feature of Douglas and Wildavsky's Cultural Theory was that individuals have ways of life and world views that can be defined by their position on a 2-dimensional grid along the axes "hierarchist" versus "egalitarian", and group position—"individualist" versus "communitarian". Cultural Theory claims that risks are selected to preserve our ways of life, and hence disputes over risk are disputes over ways of life. Accordingly, as ways of life and values have changed over the last 50 years towards a more individualist, entrepreneurial society, so risk perception and attendant risk management would be expected to shift from prescriptive legislation towards less prescriptive approaches. Recent developments in Cultural Cognition Theory (Kahan, 2008) have incorporated knowledge of the psychological processes that connect peoples' values to their perception of risk (Slovic, 2000), for example by accepting or dismissing information that strengthens beliefs about risk that are consistent with their values.

The evolution in regulatory approaches is sometimes described as a move to "performance-based" OSH legislation, which requires workplaces to meet certain safety standards, but does not prescribe exactly how this should be done. This shifts responsibility for safety away from regulators and towards employers and employees, based on the idea that permitting industry to self-regulate fosters greater ownership of safety by industry, and that "those that create the risk are best placed to manage it" (Robens, 1972). Rather than prescribing specific limits, regulators take on the responsibility to educate, and to develop non-statutory codes of practice, preferably in consultation with industry. Following the UK Health and Safety at Work Act (1974), similar types of OSH legislation were enacted in Canada, Australia and New Zealand.

An overarching principle is the employers' general duty of care for the safety of employees and others in the workplace, together with a mutual responsibility of employees to report fit for work, behave safely in the workplace, and contribute to safety management. The principles of duty of care, and shared employer/employee responsibility for safety and health, are integral to FRMS and the evolution of FRMS regulatory approaches has generally been more rapid in countries that have adopted these principles in their OSH legislation, by comparison with countries that have not, for example the USA. The redistribution of responsibility for safety and health under performance-based OSH legislation has profound implications for the level of personal responsibility of employees and for the legal liability of organizations.

In some federal systems of government such as Australia, OSH law is developed at the state level although Federal law may co-exist. In 2006, the state of Western Australia introduced a generic OSH Code of Practice on working hours (Code of Practice-Working Hours) amid concern in many quarters that employees and contractors were working excessive and unsafe hours in the mining and construction industries (Hartley et al., 2005). This code sought to provide guidance to all industries, including transport, on the risks associated with the duration and timing of work and sleep, and to encourage stakeholders to develop industry-specific codes to manage these issues.

In contrast, the United States has a centralized regulatory framework for hours of service and OSH which states cannot dismiss, although they can impose more restrictive regimes. The European Union generates Directives that the member countries must then ratify and incorporate into their own regulatory structure.

2.2. Hours of service regulations in transport

Particular safety concerns in regard to the working hours of transportation operators have been recognised since the 1930s. Regulations limiting hours of work and minimum rest periods have developed in many countries, usually under the auspices of separate agencies for each mode of transport. In addition, the United Nations has agencies to develop international regulatory frameworks for aviation operations (International Civil Aviation Organization) and maritime operations (International Maritime Organization).

This section summarises the HoS regulations in effect in the four transport modes (commercial road transport, rail, aviation and maritime operations) in five main geographical zones (reflecting the experience of the authors) namely: Australia, European Union, New Zealand and USA. In addition, some recent initiatives from Transport Canada are described, as it moves away from being the owner/operator of major parts of the transportation system towards a role focused on policy and regulatory oversight.

2.2.1. Commercial road transport

In 1938, the USA regulated to limit commercial drivers to 12 h driving and 15 h of work, with a minimum of 9 h rest in the 24 h cycle. The legislation followed the prevailing regulatory climate in seeking to balance working conditions and remuneration (drivers were paid by miles driven). Pressures back and forth between the labour unions and the enforcing agency (the Interstate Commerce Commission) lead to subsequent changes. From the perspective of a modern understanding of the causes of driver fatigue, many of these changes may not have improved safety, for example enabling non-24-h work/rest cycles and splitting minimum rest periods.

In the following decades, similar legislation was enacted by government agencies in other countries including Canada, the UK, Australia and New Zealand. In some countries with a federal structure (including Canada and Australia), the legislation was enacted at state level, leading to a mix of regulated and unregulated states.

Debates over driving HoS limits continue. In 2003, the US Federal Motor Carrier Administration (FMCSA) reduced daily working hours to 14, and limited driving time to 11 h (or 77 h over 7 days). In 2007, a Federal Appeals Court struck down the 2003 regulation, arguing that the FMCSA had not provided sufficient justification for the revision. In particular the court believed FMCSA had ignored its own database showing that the extra hours of service would increase fatigue-related accidents. In addition, FMCSA was admonished for not adhering to its own mandate of looking at the safety and health of both the drivers and the public.

These debates are not unique to the USA, and different countries have different limits. For example, European regulation No. 561/2006 sets the daily driving limit at 9 h, extendable to 10 h no more than twice per week. In 2004, Canada amended its federal HoS limits for commercial vehicle drivers to 13 h of driving and 14 h of duty per 24 h, thereby increasing the minimum off-duty period from 8 h to 10 h per 24 h. In New Zealand, legislation enacted in October 2007 abolished the differentiation between driving hours and duty hours, limiting both to a maximum of 13 h per 24 h, with a break of at least 30 min after each 5.5 h of work and a requirement for a minimum 10 h break per 24 h (previously 9 h).

The new legislation in New Zealand also includes a concept that is starting to appear in regulations, namely the notion of "chain of responsibility" offences. A person who employs or controls drivers subject to the HoS limits can be fined up to $25,000 if they knew, or should have known, that a driver under their control breached those limits. Chain of responsibility offences are also enacted in the Australian federal trucking regulations. They expand accident investigation and culpability beyond the traditional focus on active errors made by individuals, to also addressing latent organizational errors that may have contributed (Reason, 1997).

2.2.2. Rail

The history of HoS regulations in the UK rail industry illustrates an evolution from reactive change in response to major accidents, to a regulatory framework for fatigue risk management systems with supporting guidance materials. After a train collision near Thirsk in 1892,[1] in which 10 people died, an official inquiry identified the signaller's fatigue as being a contributory factor and recommended that a "tour of duty of 10 h is the outside which ought to be allowed in mainline signal cabins". However, it was not until 1919 that the trades unions negotiated a national railway industry agreement limiting rostered work to a maximum of 8 h per day.

A serious rail accident at Clapham Junction, in which fatigue of a signal maintainer was found to be one of the underlying causes, lead the British Railways Board to introduce an industry set of maximum limits on working hours (Hidden, 1989). The limits were generic and reflected what was achievable in operational terms at the time, based on expert opinion and agreed good practice. While the limits were not mandatory, companies monitored employees using the limits as a standard, and had systems to identify breaches.

In 1994, the Railways Safety Critical Work regulations[2] introduced the first legal requirement on railway employers to ensure that, so far as is reasonably practicable, "no employee of his undertakes any safety critical work for such number of hours as would be liable to cause him fatigue which could endanger safety; and in determining whether he would be so liable regard shall be had to the length of time between periods on duty". To help companies meet this requirement, the UK Health and Safety executive commissioned the development of a method[3] to assess the risk arising from fatigue associated with work patterns for safety critical workers, which has been widely adopted in the rail industry.

More recent legislation implementing aspects of the European Railway Safety Directive has superseded the Railways Safety Critical Work regulations, and introduced guidance for fatigue risk management systems. This is described in more detail below.

In Australia, individual states have their own legislation governing rail transportation – the Railway Safety Acts dating from early 1990s – as well as being subject to federal regulations. The Railway Safety Act of New South Wales refers to the hazard of working hours and the requirement to manage fatigue. Other state Rail Safety acts refer to the need to have a safety management system complying with relevant Australian Standards. In 2006, the Australian Government National Transport Commission introduced model rail safety legislation, which will be given legal effect when its provisions are reproduced in the legislation of each State. The new legislation specifies the need for rail operators to provide for the management of fatigue of rail safety workers in an overall safety management systems approach.

The US Federal Railroad Administration (FRA) has a dual role, namely: (1) a safety focus—developing and enforcing safety rules and regulations and (2) an economic focus—supporting industry development through railroad assistance programs, conducting research and development, and coordinating other government support for railroad activities. The safety issues currently facing the FRA mirror those in other transport sectors. From 1990 to 2004, there has been a significant reduction in track-caused accidents and in equipment-caused accidents, but the number of accidents caused by human factors, including fatigue-related accidents, have remained constant and accounted for 38% of all train accidents in the last 5 years.

In response to these trends, and to the need to improve safety in the face of projected industry growth, the FRA is moving away from its historical focus on regulations targeting conditions and equipment towards promoting a more comprehensive safety systems approach that aligns: (1) the maintenance systems that provide safe working conditions and equipment; (2) the human capital systems that manage human resources and motivate safety improvement activities (i.e., recognition, rewards, incentives, and promotion); and (3) the organizational systems that influence safety climate and culture.

2.2.3. Commercial aviation

In commercial aviation operations, the main regulatory mechanism for addressing pilot fatigue remains prescriptive rules limiting flight and duty time, aiming to provide for adequate rest (International Civil Aviation Organization, 2006). Revisions to these rules have recently been implemented in Annex 6. ICAO also has an initiative in progress to develop a regulatory framework for fatigue risk management systems in aviation (described in more detail below). The ICAO regulatory frameworks are widely implemented by Member States, in contrast to the initiatives of some other UN regulatory agencies.

In 2006, after about a decade of debate and negotiation, the European Commission adopted a regulatory framework that harmonizes the flight and duty time limitations among the European states (sub-part Q of the EU-OPS 1). Since 16 July 2008, all EU states have had to implement this new regulation. In parallel, a scientific and medical evaluation of the new regulation is under way that will be completed by 16 January 2009. The evaluation is being conducted by the European Committee for Aircrew Scheduling and Safety[4] (ECASS).

The new European regulatory framework includes a number of provisions that are not common in traditional transport HoS regulations (Cabon et al., 2002). These include consideration of the effects of the circadian biological clock, by having specific provisions for operations that encroach on the "window of circadian low" (WOCL), defined as 02:00–05:59. The new framework also allows increased flexibility. A national regulatory authority may grant variations under the following conditions.

> "Each operator will have to demonstrate to the Authority, using operational experience and taking into account other relevant factors such as current scientific knowledge, that its request for a variation produces an equivalent level of safety. Such variations will be accompanied with suitable mitigation measures where appropriate".

Each national authority is responsible for demonstrating to the European Aviation Safety Agency that a variation it has granted is compliant, i.e., that it produces a level of safety equivalent to that resulting from compliance with the prescriptive flight and duty time limits. (EASA is not providing guidance to the national Authorities around the approval of exemptions.) In effect, this represents the first step towards enabling fatigue risk management systems.

All of the preceding examples apply to flight crew. In 1991, the UK Civil Aviation Authority implemented the Scheme for the Regulation of Air Traffic Controllers' Hours (SCRATCOH), which had not previously been regulated. Although the approach imposed HoS limits, it was recognised that there was a need for a mechanism for "sensible but sparing modification", given the variety of

[1] Board of Trade inquiry 9th December 1892 inquiry into the collision between Ottering and Thirsk Stations.

[2] The Railways (Safety Critical Work) Regulations 1994. Her Majesty's Stationary Office. ISBN 0110432991.

[3] http://www.hse.gov.uk/research/rrhtm/rr446.htm.

[4] ECASS is composed of teams at 5 research institutes : Karolinska Institute (S), LAA—University Paris Descartes (F), QinetiQ (UK), DLR (G) and the TNO (NL).

air traffic control units that the regulations would cover, and the rapid pace of change in the aviation industry. Modifications were intended to enable ATC providers to overcome short-term, temporary, and unforeseen circumstances, while maintaining safety. When the scheme was evaluated in 1997 (Spencer et al., 1997), over half the airfields covered by the regulations had modifications approved by the UK CAA, highlighting the difficulty of developing one-size-fits all regulations for the diverse operations undertaken in the air traffic control industry.

The aviation industry evolves very rapidly and the rate of evolution of national flight and duty time regulations is often very slow by comparison. In February 2008, the US National Transportation Safety Board issued a Most Wanted Transportation Safety Improvement notice for aviation that sought to reduce accidents and incidents caused by human fatigue. The stated objectives included to "set working hour limits for flight crews, aviation mechanics, and air traffic controllers based on fatigue research, circadian rhythms, and sleep and rest requirements". This reflects widespread concern about the slow rate of regulatory development by the Federal Aviation Administration (FAA). In June 2008, the FAA convened an Aviation Fatigue Management Symposium that focused on causes of fatigue and barriers to mitigation strategies.

2.2.4. Maritime operations

In the maritime sector, there have been a number of international initiatives seeking to set prescriptive limits on the work and rest hours of seafarers, with a particular focus on watch keepers (reviewed in Gander, 2005). Since the early 1990s, the International Maritime Organization (IMO) has adopted a number of Resolutions relating to seafarer fatigue and has published guidance material for fatigue mitigation and management (International Maritime Organization 2001). The International Labour Organization Convention 180 – the Seafarers' Hours of Work and Manning of Ships Convention – entered into force in 2002. The European Working Time Directive 93/104/EC does not cover seafarers. However, at least two directives concerning the working time of seafarers have been adopted (Directive 99/63/EC and Directive 99/95/EC).

A number of countries have implemented regulations limiting the hours of work and rest of seafarers in some sectors of the maritime industry, including Canada, Denmark, the UK, and the USA. However, all jurisdictions seem to have struggled with developing workable prescriptive HoS regimes for the fishing industry.

2.3. Strengths and weakness of hours of service regulations

2.3.1. Perceived strengths

Hours of service regulations limit the exposure of transportation workers to some of the causes of fatigue, namely

- they limit the length of the time awake that is required for work;
- they limit the duration of continuous time on task; and
- they ensure minimum opportunities for sleep and other non-work activities.

They are generally straightforward to interpret and do not require specialist expertise to understand what is permitted and what is not. They also appear simple to enforce, by requiring transport workers and/or companies to keep records that can be inspected by the regulator or enforcement agencies such as the police.

2.3.2. Perceived weaknesses

Hours of service regulations do not limit the exposure of transportation workers to some of the major causes of fatigue, namely:

- they typically do not take account of the daily cycle of the circadian biological clock, thus overlooking;
  - the greater risk of fatigue when performance capacity is reduced during biological night;
  - the reduced recovery value of sleep opportunities during the biological day;
- they typically do not address the duty cycle, thus overlooking;
  - the rate of accumulation of sleep debt, with its cumulative, dose-dependent effects on performance capacity;
  - the frequency of opportunities for full recovery from sleep debt (a minimum of two consecutive nights of unrestricted sleep); and
- they typically do not include non-work-related time such as commuting, in the calculation of rest opportunities, and they cannot mandate behaviours and schedules outside of work.

For employers and employees, there are financial and time costs associated with keeping the required records to show compliance with hours of service regulations. In practise, as international experience with commercial truck drivers' logbooks has shown, compliance documents are fairly easy to falsify. There are incentives for employers and employees to be complicit in falsifying records, to reduce company costs and increase individuals' pay cheques. Widespread falsification of compliance documents makes it difficult to obtain adequate evidence for prosecution of breaches of the HoS regulations. One expanding approach to this problem is to supplement paper record keeping with tamper-proof electronic data collection, e.g., from vehicles. Regular scrutiny of required documentation, for example routine vetting of a large proportion of drivers' log books, might improve compliance but is extremely costly.

In developing HoS regulations, regulators are in effect challenged to develop a set of rules that will work across a diverse range of industry operations. This one-size-fits-all approach is at best a very blunt instrument for managing the risks associated with operator fatigue, and in some instances may have the unintended consequence of exacerbating fatigue. For example, in France the requirement to have additional crewmembers (augmented crew) in civil aviation is based on flight duration.[5] Therefore, in the same east-west schedule, the outward daytime flight can be augmented while the return night flight (which is shorter because of the prevailing wind) is not augmented, despite the fact that it is probably associated with greater fatigue risk. The one-size-fits-all approach can also lead to the proliferation of applications for variations or exemptions, as illustrated by the UK regulations for air traffic controllers (Spencer et al., 1997). This piecemeal modification of a regulatory framework is resource intensive for regulators and companies alike, and it is often difficult to evaluate the likely safety consequences of a series of variations which are not part of a more comprehensive safety case.

Regulatory change is a slow, reactive process and HoS regulations often lag behind rapid changes in industry practise.

Beyond these considerations, current theories of accident causation and prevention (see below) support the need for multiple layers of defensive strategies to trap failures and errors within in an organization, thereby reducing the risks associated with signifi-

[5] Décret n 97-999 du 29 Octobre 1997 relatif à la durée du travail du personnel navigant et modifiant certaines dispositions du code de l'aviation civile, Journal Officiel de la République Française, 31 October 1997.

cant hazards. Hours of service regulations represent a single layer of defence against the hazard represented by fatigued transport workers (Dawson and McCulloch, 2005). In addition, HoS regulations consider fatigue in isolation from other hazards, which is contrary to the principles underpinning modern occupational health and safety legislation.

2.4. Application of OSH legislation to transport

Two Australian States that did not have hours of service regulations for the road transport industry (Western Australia and the Northern Territory) have moved to bring the industry under the existing OSH legislation by having trucks and roads formally recognised as workplaces. Thus management of driver fatigue, as an identified hazard in the road transport industry, comes under the general duty of care in the OSH legislation. A registered "Code of Practice for Commercial Drivers" has been drawn up in these States, that outlines the hazards posed by driver fatigue and some control strategies in the industry.[6]

In New Zealand, the general OSH legislation was amended in 2003 to include aircraft, motor vehicles, locomotives, and maritime vessels as places of work. Fatigue and shift work were also explicitly recognised as hazards that must be managed in all workplaces. Responsibility for the implementation of the OSH legislation in the different transport modes was delegated to the agencies already tasked with regulating each mode (Land Transport, Maritime New Zealand, and the Civil Aviation Authority).

For road transport, current national strategies for managing fatigue in both Australia and New Zealand incorporate the OSH legislation, enabling a more flexible, goal-setting approach that recognizes the multiple factors which can cause fatigue and reduce safety in the industry. Interestingly, the Australian Medical Association has also developed a code of practice for rostering and shift work for hospital doctors, based on the duty of care requirements in the OSH legislation (AMA, 2005; Gander et al., 2007).

The Transport Canada Aviation Occupational Health and Safety Program began in 1987. The program is seen as being responsible for many positive changes, such as Air Transat's implementation of a reporting system that balances open (though not anonymous) reporting of risks with appropriate disciplinary measures if warranted. This system is based on a formal understanding between management and employee representatives that provides immunity from corporate disciplinary measures (though not from regulatory or legal penalties) for those who report safety-related information.

2.5. Fatigue risk management regulatory approaches

2.5.1. Aetiology of accidents and defences in depth

As a conceptual framework for developing fatigue risk management systems, Dawson and McCulloch (2005) have adapted Reason's (1997) hazard control framework. A fatigue-related incident/accident can be viewed as the final point of a causal chain of events or 'hazard trajectory' that penetrates all the defences present in the system to control that hazard.

Dawson and McCulloch identified a series of defensive layers that can be implemented to limit the likelihood of fatigue-related incident event or accident occurring (a defences-in-depth approach).

- Level 1 defence involves providing adequate opportunities for sleep, including recognising the importance of the placement of sleep opportunities with respect to the circadian cycle. This is the level partially addressed by traditional HoS regulations.
- Level 2 involves processes for confirming that adequate sleep is obtained.
- Level 3 involves processes to detect and prevent behavioural symptoms of fatigue.
- Level 4 involves processes for detecting fatigue-related errors.
- Level 5 involves processes for investigation of fatigue-related incidents and accidents.

The power of the defences-in-depth approach can be illustrated by considering a hypothetical example. In a system with a single layer of defence with very high sensitivity (e.g., 90%), fatigue will not be detected in 10% of cases when an individual is in fact fatigued. By comparison, in a system with four independent layers of defence each with only moderate sensitivity (i.e., 50%), fatigue will not be detected in only about 6% of cases when an individual is in fact fatigued. A system with multiple defensive layers, albeit each imperfect, will capture more potential fatigue-related incidents than a system with only one highly specific defensive layer. In keeping with this conceptual framework, the definition of a fatigue risk management system used here is:

> A scientifically based and flexible alternative to rigid work time limitations, that provides a layered system of defences to minimise, as far as is reasonably practicable, the adverse effects of fatigue on workforce alertness and performance, and the safety risk that this represents.

A full-scale FRMS is a partnership between management and workforce that uses safety management systems and processes to continuously monitor and manage fatigue risk (see below). The following sections offer examples of some of recent regulatory initiatives that enable FRMS as an alternative to HoS regulations in transport operations.

2.5.2. Commercial road transport

In February 2007, the Australian Transport Council agreed to introduce fatigue risk management systems in road transport. This allows operators to seek accreditation in the National Heavy Vehicle Accreditation Scheme (NHVAS), allowing them to have drivers working outside the limits contained in each State's HoS regulations, under specified conditions. The NVHAS offers a staged approach that enables operators to move progressively further outside the HoS limits, through two levels of fatigue management systems.

In the Basic Fatigue Management (BFM) regime, drivers are still limited to 14 h work per 24 h, but with greater flexibility than under the Standard Hours regime. To manage the additional risk, operators must comply with six BFM standards covering scheduling and rostering, fitness for duty, fatigue knowledge and awareness, responsibilities, internal review, and records and documentation.

In the Advanced Fatigue Management (AFM) regime, operators develop a customised and auditable safety management system with controls specific to the fatigue risks of their particular operations. The FRMS must address the parameters listed in the following table, specifying normal operating limits, how often these are likely to be exceeded, and the mitigation strategies that will be implemented to manage the enhanced risk when normal operating limits are exceeded (e.g., longer rest breaks to balance more night driving). Operators may not exceed the outer limits, which are based on robust advice from fatigue experts and experience from current transport industry practices.

A further requirement is that key members of the organization must be trained to have the knowledge and skills to manage fatigue.

[6] Available at http://www.docep.wa.gov.au/worksafe/PDF/Codes_of_Practice/Fatigue_managment_fo.pdf.

2.5.3. Rail

In 2008, the UK introduced new legislation[7] that requires all Class 1 railroad carriers to have railroad safety risk reduction programme that includes a fatigue management plan that is updated at least every 2 years and which is subject to review and approval by the Secretary of Transportation. The plan must take into account the varying circumstances of a carrier's operations, and have appropriately targeted fatigue countermeasures. It must address employee education and training, medical conditions that may affect alertness or fatigue, responses to emergency situations, scheduling practices, times of increased risk in the circadian cycle, strategies to improve alertness on duty (e.g., napping), opportunities for restful sleep (including employee sleeping quarters provided by the carrier), the duration of rest periods completely free of work demands, avoidance of abrupt changes in duty/rest cycles, and any additional elements that the State considers appropriate. Workforce consultation and good faith negotiation are required to achieve consensus on the plan, and dissenting views submitted to the Secretary of Transport will be taken into consideration for approval of the plan.

In Australia, the Federal model Rail Safety Bill (2006) requires rail operators to have a safety management system that includes a fatigue management programme for safety-critical rail workers. A detailed guideline was released in June 2008 (National Transport Commission, 2008) to assist the industry and regulators to develop fatigue risk management systems. The approach proposed closely follows the model developed for ultra-long range aviation operations (Flight Safety Foundation, 2005), and outlined later in this paper.

In Canada, the rail system has undergone major changes since the early 1980s, as the result of privatisation and deregulation. Private operators seeking greater efficiencies and profitability have closed down large quantities of track in some areas and expanded services in others, in response to increasing demand for freight services. In this dynamic environment, the federal Railway Safety Act (1989) was amended in 1999 to require railway companies to develop and implement safety management systems. The SMS regulations came into force on March 31, 2001 and were the first federal regulations of their kind in the Canadian transport sector. Subsequently, the weakest component in the implementation of SMS was identified as effective management of human and organizational factors, with companies performing better in the areas where they have traditionally focused their safety effort, i.e., technical and equipment aspects of their operations. Consequently, new rules governing maximum hours of work and minimum undisturbed rest periods were put in place in 2003. The new regulations require companies to file a general fatigue management plan, and specific plans if they wish to exceed the HoS limits.

In the USA, the Federal Railway Administration is encouraging a number of fatigue risk reduction initiatives through its development role. These include:

- Encouraging the use of upstream (predictive) data to monitor and manage safety activities, rather than relying solely on after-the-fact accident and injury statistics. This will include better data surveillance systems that enable inspectors, companies and personnel to better understand where fatigue is an issue.
- Providing encouragement, promoting knowledge sharing, and offering appropriate incentives to encourage additional safety effort, including the opportunity to apply for variations where existing regulations may thwart a proposed safety initiative.
- Removing barriers to voluntary proactive risk management programs. The FRA is trying to help to identify systemic issues (real and perceived) that inhibit the adoption of voluntary safety improvement efforts, and where it can help to eliminate these barriers.
- Promoting cooperation and collaboration in the safety field, emphasising the common interest of management and labour in improving safety.
- Helping to improve safety culture within railroads by promoting labour-management cooperation, innovative voluntary safety programs, improved communications, and better use of data.

[7] Public Law 110-432-Oct 16, 2008.

2.5.4. Commercial aviation

In March 2006, the International Civil Aviation Organization (ICAO) established a Fatigue Risk Management Sub-Group (FRMSG) of the Operations Panel to develop a regulatory framework for fatigue risk management in commercial aviation. The starting point for the FRMSG was the model developed for ultra-long range flight (Flight Safety Foundation, 2005), and this work is ongoing. It is expected that the ICAO framework will include FRMS as part of a company's safety management system, for which ICAO requires implementation by 2009.

The new European regulatory framework for flight and duty time limitations (sub-part Q of the EU-OPS 1) allows national regulatory authorities to grant variations to the prescriptive flight and duty time limits, but the authority is also responsible for ensuring that appropriate mitigation strategies are in place. In 2007 and 2008, France issued regulations that describe the main components of an FRMS, and the mitigation measures that should be used to compensate for reduced rest and split duty periods. The French Civil Aviation Authority has also initiated a large research program to develop the scientific basis for a comprehensive FRMS for French regional airlines (Cabon et al., 2008).

In 1995 the regulations governing the New Zealand aviation industry were altered, so that air operators could meet the flight and duty time limits by either complying with a standard prescriptive flight and duty hours scheme (detailed in Advisory Circular 119-2), or by applying to the New Zealand Civil Aviation Authority (NZCAA) to have an alternative, company-specific scheme approved. In alternative schemes, operators must consider additional factors that may result in fatigue, such as: rest periods prior to and in flight; effects of time zone changes and night operations; crew composition; type and amount of workload; and the cumulative effects of work. Within this regulatory framework, Air New Zealand has been able to develop a highly successful FRMS that has been in operation for a decade.

The Australian Civil Aviation Safety Authority is currently developing a rule and advisory material to enable fatigue risk management schemes as an alternative to prescriptive flight and duty time limits for managing flight crew fatigue.

In air traffic control, the New Zealand Civil Aviation Authority in 1999 issued a draft rule for fatigue management that allowed air traffic services providers to comply either by observing a set of prescriptive HoS limits, or by implementing their own fatigue risk management schemes. To comply, schemes were required to take into account seven specified factors, including workload, patterns of breaks, staffing levels, short-term and accumulated sleep loss, and circadian rhythms, and to specify limits on a number of duty-related variables (proposed by the operator rather than imposed by the regulator, in a similar manner to Table 1 above). Guidance material was developed in consultation with industry, which provided an example of an acceptable fatigue management scheme that would comply with the requirements of the rule (Gander, 2001). However, neither the rule nor the advisory circular has yet been enacted.

Table 1
Advanced Fatigue Management parameters from the Australian federal road transport regulations.

Parameter	Normal operating limits	Frequency for exceeding normal operating limits	Outer limits
Minimum break in a 24-h period	Operator to propose	Operator to propose	6 continuous hours or 8 h in 2 parts
Minimum continuous 24-h period free of work	Operator to propose	Operator to propose	4 periods in 28 days
Minimum opportunity for night sleep (between 10 p.m. and 8 a.m.)	Operator to propose	Operator to propose	2 periods in 14 days
Maximum hours work in a 24 h period	Operator to propose	Operator to propose	16 h (except NSW and Victoria)
Maximum work in 14 days	Operator to propose	Operator to propose	154 h
Maximum work in 28 days	Operator to propose	Operator to propose	288 h

2.5.5. Maritime operations

In New Zealand, when the 2003 amendments to the OSH legislation extended its coverage to include maritime vessels, Maritime New Zealand was charged with implementing strategies to manage fatigue in the maritime sector. It was decided not to develop HoS regulations (none existed for the majority of vessels that fall outside the IMO Convention for the Safety of Life at Sea; SOLAS, 1974). Instead, the regulator chose to assist the sector to develop fatigue risk management programmes that build on an existing safety management system required for the certification of all commercial vessels, known as the Safe Ship Management Programme (Wayne Perkins, MNZ, personal communication).

The mandatory Great Barrier Reef Pilotage Safety Management Code (Australian Maritime Safety Authority, 1999) requires that all persons, procedures, and operations involved in coastal pilotage must be covered by an approved safety management system, which must include a fatigue management plan.

2.6. Summary: regulatory approaches

As the above examples illustrate, regulatory frameworks that permit FRMS as an alternative means of compliance to HoS are spreading across the transportation sector. HoS regulations are generally described as prescriptive, while the FRMS approach is considered more aligned with performance-based legislation for occupational health and safety. Nevertheless, most FRMS regulatory regimes specify some limits that must be addressed (for example Table 1). However, in FRMS limits are proposed by the operator whereas in HoS they are imposed by the regulator. In addition, FRMS regulations typically specify a number of other essential risk mitigation strategies in addition to limits on work scheduling, for example education and training for relevant staff, systems for ongoing monitoring of fatigue levels, and systematic analysis of the role of fatigue in safety incidents.

3. Industry/company level organizational factors

Industries and companies must operate within the applicable regulatory schemes to meet the required safety standards. As described above, FRMS shifts the locus of responsibility for fatigue risk management away from regulators and towards employers and employees. Thus, it is becoming increasingly important to understand the organizational factors at the industry and company level that influence effective fatigue risk management.

3.1. Operational complexity, reliability, and fatigue risk

Fatigue risk management systems are often envisaged as an integral part of broader safety management systems. The nature of a company's SMS depends on the industry, and will vary as a function of the level of reliability required (in transport versus nuclear power, versus healthcare, etc.). Amalberti (2001) identifies three categories of systems, depending on the probability of an accident per number of events (i.e., the number of system "initiations", such as the number of aircraft take-offs in aviation):

1. dangerous systems (one accident per 1000 events—these are mostly non-professional systems);
2. regulated systems (one accident per 100,000 events, e.g., driving, chemical industries, etc.); and
3. ultra-safe systems (one accident per one million events, e.g., scheduled commercial aviation, railways, nuclear power industry).

A key feature that distinguishes ultra-safe systems is the fact that accidents may occur in the absence of any serious operator error. Accidents result from a combination of factors, each of which alone is not sufficient to provoke the event, and thus they are relatively unpredictable. In less reliable systems (dangerous and regulated systems), accidents often reflect previous events or incidents, and thus patterns of risk may be more predictable than in ultra-safe systems.

This difference affects safety management strategies. In regulated systems, safety management largely relies on reporting, to reduce the likelihood of similar incidents or accidents occurring. In ultra-safe systems, this reactive approach to safety has to be complemented by a proactive approach that relies not only on reporting, but also on hazard identification and risk mitigation strategies.

This evolution in safety management mirrors evolution in understanding of the role of human error in system safety. Human error can have a direct impact on safety in regulated systems (e.g., failure to stay in the correct lane on a road). However, human error is increasingly considered as a consequence of a deeper failure in the system, rather than as a simple cause of an accident. From this perspective, human error is the starting point for safety analysis, rather than the end point (Dekker, 2005). Thus, safety management in ultra-safe systems focuses not only on the occurrence of errors, but also on the context in which errors occur, and on the development of systems that minimize the safety consequences of error, and that are resistant to the effects of variability in human performance.

The required level of reliability in an operation also affects the proportion of accidents in which operator fatigue is likely to be identified as causal. For motor vehicle crashes, there is a reasonable consensus that about 15–20% involve driver fatigue (Maycock, 1996; Horne and Reyner, 1995; Gander et al., 2006). These accidents are mostly attributed to one component of fatigue (drowsiness) that leads to typical accident features such as lack of skid marks and signs of braking (Horne and Reyner, 1999). In highly protected and more complex systems such as rail or aviation operations, it is much more difficult to establish the proportion of accidents that involve operator fatigue. For example, in aviation, estimates range from 3.8 to 21% (National Transportation Safety Board, 1999). This is because in the safest systems, the link between human performance and accidents is less clear. Multiple layers of operational defenses such as automation, team work, and procedures, reduce the probability of having an accident attributable to a unique cause.

In these complex systems, fatigue is typically only one of multiple contributing factors.

This emphasizes the need for developing reliable surveillance systems, and analysis methodology that can accurately evaluate the contribution of operator fatigue to accidents in complex systems and, above all, that can identify the conditions and contexts where operator fatigue can jeopardize safety. Without this information it is impossible to establish a baseline against which to evaluate the performance of FRMS, or to develop a robust business case for the benefits of implementing an FMRS.

3.2. Culture

3.2.1. Safety culture and organizational culture

The development of a mature "safety culture" is vital to safety management systems (Reason, 1997), and this applies to FRMS. Such a culture approaches safety lapses and errors as opportunities to learn safety lessons, and has the following key characteristics.

- All hazardous incidents and near misses are reported and investigated (a reporting culture). Steps to encourage a reporting culture include: making it easy to report; timely, informative feedback to the reporter on action taken; indemnity against disciplinary action unless the event involves deliberate violation, and ideally the opportunity for confidentiality and anonymity, which may necessitate the separation of the reporting agency from the disciplinary agency.
- Widely agreed rules exist for taking visible disciplinary action, which include discussion of when disciplinary action is required and when not (a just culture). It has been argued that culpability should be restricted to instances of risk-taking behaviour, reckless acts (intentionally violating rules), and failure to report (or attempting to conceal). These actions are distinct from accidental errors or violations that are identified and reported.
- Multi-skilling of individuals and encouraging diversity among employees, so that a wide range of skills and abilities are present to enable an organization to adapt to problems (a flexible culture).
- Steps are taken to act on information in a timely and appropriate manner (a learning culture).

The cost of implementing a safety culture is often perceived as a barrier, but robust cost-benefit analysis may help to overcome this, since ultimately a system with more accidents is likely to prove more expensive than one with a strong safety system. Such analysis requires tracking appropriate indicators to demonstrate safety performance. Modern approaches emphasise the use of "lead indicators" (those which appear early in the genesis of risk), rather than the more traditional focus on "lag indicators" (including actual incidents) which appear later and often require a more urgent response. Operator fatigue is a good example of a lead indicator, and responding to it can be viewed as a proactive or even preventive measure, rather responding reactively to fatigue-related safety incidents (Reason, 1997; Hartley and Arnold, 2001).

A culture of mistrust between employees and management in an organization clearly creates barriers to developing a safety culture. Thus the prevailing industrial relations environment may need to be considered carefully at an early stage of FRMS implementation. Conversely, building a collaborative FRMS may be a valuable step towards improving trust between management and employees (Hartley and Arnold, 2001). In the UK rail industry model, consultation with safety critical workers is regarded as crucial to the success of FRMS. In addition, consultation is required with relevant third parties, such as trade unions and the safety regulator. The challenge of getting union buy-in can be significant even in a single company, when there are a multitude of variable, locally negotiated sets of working conditions.

In the United States railroad industry, there have been structural/policy barriers to developing a safety culture. The Federal Employers Liability Act (FELA) is an alternative protection scheme to the Workmens' Compensation Act that is used by most other employers. FELA requires the assignment of blame, and that the specific railroad pays out to the employee a sum equivalent to the share of the blame for which they are judged responsible. As a result, the assignment of blame becomes a litigious exercise often involving large sums of money, and the employee is often out of work until the case is resolved. This approach to compensation breeds mistrust. On the other hand, there are examples of successful safety-focused initiatives, such as the FRA's Close Calls Reporting System.

3.2.2. National culture and ethnicity

In addition to organizational culture, national or ethnic culture may be an important factor affecting successful implementation of FRMS. An international survey of flight crew (Bourgeois-Bougrine et al., 2000) showed effects of national culture on the perception of fatigue and coping strategies to reduce it. This suggests that some recommendations will be more readily adopted in some countries than others.

It has also been observed that some ethnic and national groups are less comfortable challenging authority and potentially less likely to report concerns or hazards. This may have an important effect on the reporting methods adopted, as well as the types of education programmes employed (Helmreich and Merritte, 1988). Cultural differences at this level may mean that a system that works well in one setting may not be able to be replicated in a similar organization in a different country, or in an organization with a different ethnic mix of employees. An understanding of cultural influences is therefore an important consideration in designing an effective FRMS. This underscores the need for active employee involvement in the development and implementation of FRMS.

3.3. Remuneration and disincentives for safe behaviour

As described previously, much OSH legislation since the 1970s has sought to separate safety and health issues from industrial issues and remuneration, since these two sets of concerns can be diametrically opposed—one emphasizing protection and the other production. Historically, work that was more unsafe sometimes attracted higher remuneration and/or remuneration methods fostered less safe practices. For example, the common practice of paying truck drivers by the distance travelled, or by the load delivered, can encourage speeding and excessive hours of work and has been identified as contributing to major truck crashes (National Transportation Safety Board, 1995). Likewise, overtime penalty rates may encourage people to work longer hours and affect their decision making around personal safe limits (Gander et al., 2005a,b).

In its investigation of a head-on train collision (resulting in 4 deaths, 2 seriously injured crewmembers, and an estimated $4,400,000 in damages) the NTSB highlighted a number of specific organizational policies that effectively discouraged safe decision making by the fatigued locomotive engineer who failed to stop his train in a siding (NTSB, 1991). The engineer had accepted a call back at a destination layover, after initially indicating that he was too tired to take the trip. Had he refused the call back, the consequences were many: e.g., he would have lost income; he have had to find his own transport back to home base; if no other engineer could be found to take his place, then the remainder of his crew would also have lost pay; and he faced possible disciplinary action because he had previously refused assignments twice when on call.

Promotion and seniority policies can also be unintended drivers of unsafe practices, for example by encouraging less experienced staff to work longer hours or more arduous schedules with inadequate supervision. In some careers, there may be a perception that it is necessary to endure fatigue as a proving ground to justify later promotion. Extended hours of work during medical training are sometimes viewed as a "rite of passage" of this sort.

In commercial aviation, it is common for more experienced pilots to have priority in bidding for monthly trip patterns and to be flying more physiologically challenging long-haul trips (Gander and Signal, 2008). If retirement income depends on earnings in the final years of career, the likelihood of fatigue may not be the main driver of an older pilot's choice of trips. Conversely, those at the bottom of the bidding order are usually younger and may have little flexibility in selecting trip patterns that minimize their fatigue or meet the needs of family life. A particular issue in transport operations is the additional workload and time demands placed on employees who have managerial or office-based responsibilities, in addition to acting as transport crew.

A number of more general trends in employment practices have the potential to exacerbate fatigue risk, notably the increase in contracting-out and the casualisation of work. Employees in precarious work may be less likely to complain about excessive work hours or unrealistic schedules, and these work practices are much more likely to go undetected by enforcement agencies than they would in more formal employment situations. An associated phenomenon is "presenteeism", or the perceived need to be present at work, even when unwell or beyond legal or safe limits on work hours.

Down-sizing and short-staffing also exacerbate pressure on the remaining workforce to make choices that are not necessarily consistent with good fatigue risk management. A study in the UK rail industry found that the most frequently cited risk in current scheduling practices was staff shortages, causing staff to have to work longer and more frequent shifts. Companies often cite lengthy training periods and shortages of skilled, competent labour as barriers to implementing good practice in fatigue risk management. Inadequate planning for large-scale retirement in an aging workforce can also lead to significant shortages of skilled labour. In addition, most workforces include "the hungry few" who seek to work as much overtime as possible. In many of the companies interviewed in the UK rail study, certain staff members were more likely to be at the maximum permitted number of hours, indicating a need "to protect staff from themselves" (McGuffog et al., 2005).

In some occupations, it may not be possible to make a viable profit, or to earn a reasonable living, by working reasonable hours. This can be exacerbated as an unintended result of regulatory change. For example, after the New Zealand taxi industry was deregulated in 1989, there was a rapid increase in the number of cabs for hire, leading to complaints by drivers that they had to work excessive hours to make a living and pay off their cars (Firestone, 2005). The regulator has subsequently capped the number of taxi licenses that are issued at any one time.

3.4. Commuting

Commuting time reduces the time available for recovery sleep and all other non-work activities. In airlines, it is not uncommon for crews to live in another city or even another country from their flying base. Long distance commuting is fatiguing in itself, as well as encouraging the grouping together of work duties to maximize the number of consecutive days off. A related consideration is secondary work, which may be encouraged by the availability of long periods off duty.

Extended driving to and from work also poses hazards to both the commuter and other road users. For example, in a recent national survey of junior doctors in New Zealand, 24% reported having fallen asleep at the wheel while driving home from work, since becoming a doctor (Gander et al., 2007). Exposure to this risk was much smaller when they were required to live on the hospital campus, but this is no longer the case. A small study of train dispatchers (signalers) found a nonlinear relationship between length of commute and both the reported level of fatigue upon reaching the workplace and pace at which reported fatigue accumulated over the course of the work shift (Popkin, 1999).

Depending on the specific profile of the workforce and the potential for increased fatigue risk, it may be appropriate to have company policies around commuting and secondary employment, and to address these issues in fatigue risk management education and training.

3.5. Sleep disorders and FRMS

A comprehensive FRMS should include policies to address the management and return to work of employees who have chronic sleep problems that increase the risk of fatigue-related accidents for themselves and others. Long waiting lists and the cost of specialist sleep medical services can be a significant disincentive for disclosure by an employee who is experiencing chronic sleep problems. In some jurisdictions, road transport regulators are introducing license restrictions for commercial drivers with suspected or untreated sleep disorders, and the spectre of loss of income can be an important additional disincentive to seeking treatment (Firestone et al., 2005).

To manage these risks, strategies include ensuring that diagnosis and treatment are available in a timely manner and that there is a clear policy around conditions of return to work. For example, in response to information that a significant proportion of locomotive engineers were at high risk for obstructive sleep apnoea, the then New Zealand rail operator provided vital start-up funding for the establishment of a sleep disorders clinic, with the condition that a fixed number of bed-nights per year were reserved for diagnosis and treatment of their engineers, at the company's expense.

A number of safety-critical transport workers are required to have regular fitness-for-duty medical examinations, but issues relating to fatigue and sleep problems are seldom addressed. For example, while pilot fatigue is an acknowledged cause of commercial aviation accidents, there is currently no requirement to consider issues associated with fatigue or sleep problems in fitness-to-fly medical assessments (Gander and Signal, 2008).

3.6. FRMS as part of safety management systems

According to Cullen (1990), safety management systems "should set out the safety objectives, the system by which these are to be achieved, and the performance standards which are to be met, and the means by which adherence to these standards is to be monitored." He also advocates the incorporation of quality assurance principles such as those in ISO 9000. The steps in safety management include hazard identification, risk assessment, defences, and recovery from incidents/accidents.

In commercial aviation, the International Civil Aviation Organization (ICAO) is requiring the implementation of SMS by 2009. Three levels are identified for hazard identification (International Civil Aviation Authority, 2006). In the context of FRMS, different tools can be used to address each level.

1. Reactive analysis based on reporting systems. Implementation of an FRMS will require current reporting systems to be expanded so that information relating to fatigue is systematically reported. This is particularly important to improve the reliability of estimates of fatigue risk.
2. Proactive analysis. This covers the analysis of normal activity using questionnaires or routine observations (e.g., Line Obser-

vation Safety Audit (LOSA) in aviation). Normal activity analysis provides information on operational factors that can increase fatigue levels or exacerbate fatigue-related safety risk. It provides much better information on trends than analysis of safety incidents or accidents, which are relatively rare events.
3. Predictive analysis whenever a significant change is introduced. For example, predictive bio-mathematical models can be used to estimate likely fatigue levels on a new route, or as a result of a significant schedule change. However, there is a need for robust validation of these models, and for clear guidance about their appropriate use in an FRMS (see, e.g., Dawson et al., 2011).

As mentioned above, the latter two levels are particularly critical for ultra-safe systems where accidents are generally not predictable from previous incidents or accidents.

Once a register of hazards has been established, risk management aims at minimizing the safety impact of those hazards (operator fatigue in FRMS) on safety. Three levels of safety management can be identified.

1. Suppression of risk, for example by eliminating schedules that are associated with high levels of fatigue.
2. Mitigation of the risk of fatigue, for example by providing additional crew members and the opportunity for in-flight rest, or ensuring that schedules include layovers that permit sufficient time for recovery sleep, or providing education to crew members on personal strategies to improve their sleep during trips.
3. Strategies to maintain operational safety when crewmembers are fatigued, for example through the use of automation, task rotation, etc. This level is critical because fatigue risk cannot be eliminated by the preceding two levels, particularly fatigue caused by non-work factors.

4. Examples of FRMS

4.1. A comprehensive model for FRMS

This section is based on a model for FRMS that was developed under the auspices of the Flight Safety Foundation[8]. It is used here with permission (Robert Vandel, personal communication), with some suggestions to expand its applicability to other modes of transport or for other safety-critical industries. This example aims to illustrate how the organizational factors indentified in previous sections might be addressed.

The Flight Safety Foundation model proposes that an FRMS should include the following essential components:

1. a Fatigue Risk Management Policy that complies with the relevant regulatory requirements and industrial agreements;
2. education and awareness training programmes;
3. a crew fatigue reporting mechanism with associated feedback;
4. procedures and measures for monitoring fatigue levels;
5. procedures for reporting, investigating, and recording incidents that are attributable wholly or in part to fatigue;
6. processes for evaluating information on fatigue levels and fatigue-related incidents, undertaking interventions, and evaluating the effects of those interventions.

Fig. 1 proposes a possible structure for an FRMS for flight crew, which may vary for other workforces or organizations. The Fatigue Management Steering Committee is the focal point for coordinating all fatigue risk management activities within the organization. It should include balanced representation from the company and employees, with scientific/specialist advice available as needed. In addition to receiving input from others in the organization, it can choose to access a range of information sources to inform its fatigue risk management activities, and to initiate data collection if this deemed necessary.

4.1.1. Fatigue Risk Management Policy

This must be an integral part of a company's safety policy, and it must be open, transparent, and address the following elements.

- Commitment to the Fatigue Risk Management Policy from the highest levels of the organization.
- A specified line of accountability for fatigue risk management in the organization.
- Definition of the responsibilities of company management and employees.
- Identification of the work groups covered by the FRMS.
- Terms of reference for the Fatigue Management Steering Committee (FMSC), including frequency of meetings.
- Identification of fatigue reporting mechanisms.
- Policies for identifying and managing employees who are fatigued to an extent that represents a safety risk, including considering provision for opting out of an assignment.
- Commitment to provide training and resources in support of the Fatigue Risk Management Policy.
- Commitment to act on recommendations regarding fatigue risk management arising from internal audit.

4.1.2. Education and awareness training programmes

Education and training provide a common knowledge base on which to build an effective FRMS, and should include:

- explanation of the current state of knowledge about the physiological, psychosocial, and operational factors that cause fatigue;
- discussion of the specific operational hazards that are exacerbated by fatigue (for example, the effects of sleepiness on motor vehicle driving performance);
- education on the use of appropriate fatigue mitigation strategies, including strategies to assist individuals to arrive at work in the best possible (least fatigued) condition, and strategies to help maintain a safe level of functioning at work and commuting home; and
- roles and responsibilities in the FRMS, for example fatigue reporting channels, consequences of calling in too tired to work, what to do about chronic sleep problems, etc.

The content of education and training programmes, and the depth of knowledge required, may vary according to the roles of different groups in the FRMS, e.g., managers, people responsible for scheduling and workforce planning, transport operators, health and safety staff.

Education is probably the only legitimate way of addressing the potential impact of non-work activities on fatigue, through an appeal to enlightened self-interest (Gander et al., 1998). Enabling employees to develop better coping strategies, and in particular

[8] The introduction of air craft with the capability of non-stop flights in excess of 16 hours raised novel challenges for fatigue risk management in commercial aviation, including that these flights exceeded existing regulatory limits. In response, aircraft manufacturers (Airbus Industries and the Boeing Corporation) sponsored a series of four international workshops under the auspices of the Flight Safety Foundation. These workshops brought together regulators, operators, labor representatives, manufacturers, and scientists from around the world to develop a consensus approach for managing flight crew fatigue in ultra-long range (ULR) operations. At the fourth workshop, participants provided input into the development of an FRMS model (Flight Safety Foundation, 2005). This model was taken as the starting point for developing the ICAO regulatory framework for FRMS, and has influenced other regulatory initiatives, for example the Australian Federal model Rail Safety Bill (2006).

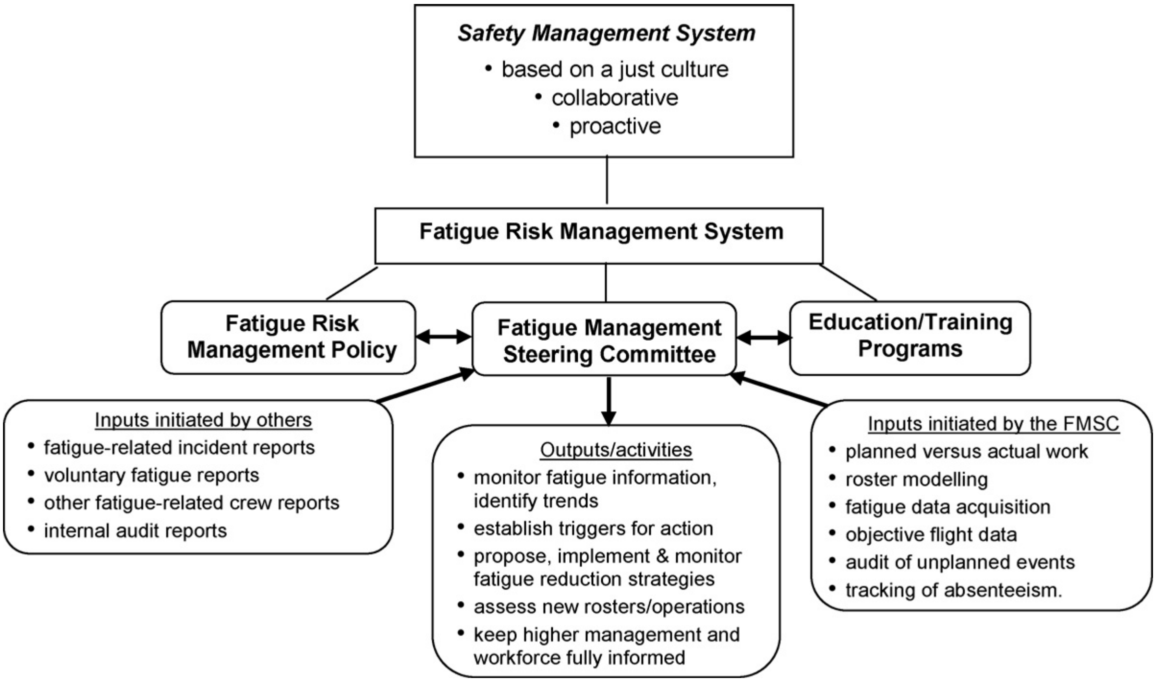

Fig. 1. The Flight Safety Foundation FRMS model.

improved sleep, can be expected to have positive effects not only on safety and productivity at work, but also on overall health and well-being outside the workplace. Education can also help counter the widely held view that fatigue is somehow an indication of personal inadequacy, rather than a normal consequence of an imbalance between the exertion of work and other waking activities, and recovery (primarily sleep).

4.1.3. Fatigue reporting mechanism(s) with associated feedback

This can be part of a wider hazard reporting system. It is vital to ensure fair handling of employees who report fatigue. Confidentiality of reporting may be an option in larger organizations, but regardless, there must be the expectation that the information will be dealt with fairly and in the interests of safety (i.e., respecting the principles of a just culture, as described above). Feedback about actions taken in response to fatigue reports, or reasons why actions were not taken, is also essential. This would be a responsibility of the Fatigue Management Steering Committee in the structure in Fig. 1.

By way of example, flight crew at Air New Zealand have been completing voluntary fatigue report forms for over a decade. Where patterns of fatigue reports are identified, more intensive monitoring may be undertaken (e.g., crew keeping sleep and duty diaries, making fatigue ratings, and undertaking performance testing across a trip). Where this has confirmed a significant fatigue issue, trip schedules have been altered.

4.1.4. Procedures and measures for monitoring fatigue levels

Voluntary fatigue reports provide one type of ongoing monitoring of fatigue risk in an organization. In addition, the Fatigue Management Steering Committee (or equivalent) may choose to gather additional information through methods such as staff surveys, in-depth monitoring of work patterns identified as potentially problematic (as described in the previous paragraph), or other routinely collected information, for example, absenteeism, staff turnover, internal and external audits, comparisons of roster and payroll data to evaluate duty swapping, etc.

A number of technologies are also being developed that aim to detect operator fatigue in real time (see Balkin et al., 2011). For example in the “PERCLOS” system, cameras monitoring eye closure can be used to trigger an alerting signal when extreme drowsiness is evident (Dinges et al., 1998). Possibilities are being explored for linking these systems with other alerting devices, for example the dead man switch in locomotives, to reduce the number of false positive alarms and the risk of habituation to alerting signals. Other devices are being trialled that measure inactivity (detected using actigraphy) as a harbinger of imminent sleep (United Kingdom Civil Aviation Authority, 2003). These kinds of devices can be used either to trigger alarms or to activate back ups in critical safety systems. However, they effectively represent the last layer of defence in a multi-layer fatigue risk management system, detecting situations where all the previous defences have been penetrated and there is imminent risk of a fatigue-related safety incident (Dawson and McCulloch, 2005). It is important in an FRMS to consider the balance of investment in technologies to detect fatigue, versus strategies to minimize it.

4.1.5. Procedures for reporting, investigating, and recording fatigue-related incidents

Establishing the role of fatigue in safety incidents and accidents is not a trivial exercise, but there are established methods for use in transportation (National Transportation Safety Board, 1994; Transportation Safety Board of Canada, 1997; Gander et al., 2006). To derive maximum information to improve FRMS, in-depth investigations need to look beyond the fatigued individual who failed in some sense, to the systems that failed to prevent that fatigue, or to mitigate its consequences.

For transport operators in a number of safety critical roles (flight crew and air traffic controllers for example), there is often a mandatory requirement to report safety incidents to the regulator. However, the severity thresholds for mandatory reporting tend to be high, and such events are infrequent. Ideally, an FRMS should have systems for capturing less severe safety breaches and tracking trends.

4.1.6. Processes for evaluating information on fatigue levels and fatigue-related incidents, undertaking interventions, and evaluating the effects of those interventions

This key element of an FRMS focuses on closing the information loops, and is a major function of the Fatigue Management Steering Committee (or equivalent). Collecting information is only the first step. The information needs to be evaluated, triggers for action identified, and where necessary, interventions to address fatigue issues need to be designed, implemented, and evaluated.

Schedule changes are a common intervention. Bio-mathematical models are being used increasingly in FRMS as a tool to evaluate and compare the likely fatigue levels across different schedules (see Dawson et al., 2011). While many other components of FRMS are essentially reactive (responding to the status quo), models provide predictions of the likely effects of schedule changes at the planning stage. All bio-mathematical models have limitations, and where large changes are planned, it may be advisable to collect data to validate predictions about the effects of a new schedule or route. This is the process that was undertaken in the validation of the first commercial ultra-long range flights by Singapore Airlines on the Singapore-Los Angeles route (Flight Safety Foundation, 2005).

Bio-mathematical modelling has been introduced as tool in the FRMS approach in the UK rail industry. This has required substantial education of the unions, as any changes to rosters or conditions that had been locally agreed could not be changed without their buy-in. Models are also used extensively in the Australian rail industry and are being introduced in the US (Drew Dawson, personal communication). The current generation of bio-mathematical models cannot be used in real time, for example to estimate workers fatigue levels when reviewing roster swaps or deciding which staff will be less fatigued when being asked to carry out overtime. This is because they are only designed to predict group averages, not individual fatigue levels. They are also based on sleep and circadian factors and do not integrate the nature of the work being undertaken and its potential impact on fatigue and safety. For example, in aviation it is well established that the level of workload and exposure to risk is not constant across a flight, but this is not taken into account by models. Current models also focus on predicting mean performance when people work alone, and do not address the implications for the functioning of multi-person crews.

In a mature FRMS, it is possible for the Fatigue Management Steering Committee to provide input into the design of schedules and rosters, based on experience and data collected previously on other schedules. This requires a high degree of confidence in the process and the Steering Committee, on the part of both management and employees. The Air New Zealand FRMS illustrates that such confidence can be developed over time with a data-driven system.

The above model for FRMS could be adapted for more traditional shift work in 24-h operations, for example in emergency services or continuous process manufacturing operations. A multi-faceted FRMS approach goes beyond the common fixation on scheduling as the primary or only fatigue risk management strategy.

4.2. Examples of FRMS

4.2.1. Commercial road transport

FRMS are increasingly being implemented in different transport modes. One of the earliest trials of FRMS was conducted in the trucking industry by Queensland Transport. Phase 1 of the Queensland pilot – the development and testing of evaluation tools – began in January 1996 (Burgess-Limerick and Bowen-Rotsaert, 2002). Currently there are four companies operating under the scheme (personal communication, Queensland Transport).

4.2.2. Rail

For the UK rail industry, the guidance to support the mandatory requirement for companies to manage fatigue in safety critical workers proposes a nine stage process (Office of Rail Regulation, 2006).

Stage 1: Identify those safety critical workers who are likely to become fatigued while carrying out their duties.
Stage 2: Identify, set, and adhere to appropriate standards and good practice for the design of working patterns.
Stage 3: Ensure that standards and limits identified in stage two are only exceeded on an infrequent basis and in exceptional circumstances.
Stage 4: Consult with safety critical workers and their safety representatives on the arrangements to manage fatigue, and particularly when standards and limits are to be changed.
Stage 5: Record the arrangements for managing risks arising from fatigue in safety critical workers.
Stage 6: Provide information to safety critical workers on risks to their health and safety posed by fatigue, and how the company is managing fatigue.
Stage 7: Monitor the effectiveness of the arrangements for managing fatigue.
Stage 8: Take action, as far as is reasonably practicable, to ensure that when safety critical workers are fatigued, they do not continue to carry out safety critical work.
Stage 9: If a company has reason to believe that their arrangements for managing the risks arising from fatigue are not effective, then they should undertake a review of those arrangements.

4.2.3. Commercial aviation

In commercial aviation, the low cost carrier EasyJet has implemented an innovative FRMS that has enabled it to work outside the current Flight and Duty Time Limitations, and to negotiate substantial savings in insurance premiums (Stewart, 2007). As already mentioned, Air New Zealand also has an established FRMS based on scientific data collection methods (subjective ratings and in-flight performance tests) to evaluate existing and new tours of duty for fatigue. The programme is managed by a collaborative crew alertness study group consisting of management, employee, and scientific representatives, with external scientific oversight. Many duties have been changed as a result of the data collected, along with a large number of other initiatives in education, training and technology. A major focus of the group has been to integrate a fatigue-predictive model into the design and construction of live aircrew rosters. Two surveys of subjective fatigue near the beginning of descent for landing have yielded data pointing towards possible approaches to flight time limitations (Powell, 2004; Powell et al., 2008). Pilot fatigue has steadily decreased through the years that the programme has been running. Fig. 2 shows results from periodic

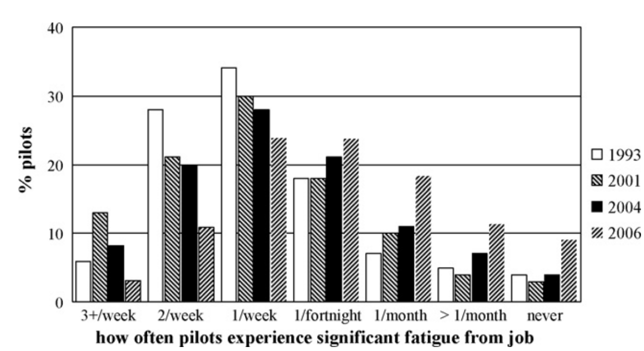

Fig. 2. Successive surveys of flight crew fatigue from the Air New Zealand FRMS.

surveys of how often flight crew experience significant job-related fatigue.

4.2.4. Maritime operations

As an example from the maritime sector, the mandatory Great Barrier Reef Pilotage[9] Safety Management Code (Australian Maritime Safety Authority, 1999, 2002) requires that all persons, procedures, and operations involved in coastal pilotage must be covered by an approved safety management system, which must include a fatigue management plan. Each pilot is responsible for his/her compliance with the provider's fatigue management system. Each pilotage provider is responsible for:

- implementing its approved fatigue management system;
- preparing rosters to cover leave for pilots, etc;
- ensuring that procedures are in place covering the reporting of matters such as near misses, accidents, equipment failures, etc. to the appropriate regulatory authority; and
- having a designated person who is responsible for verifying the effectiveness and degree of implementation of the SMS, reporting deficiencies to the appropriate level of management, and identifying people responsible for rectifying deficiencies. The designated person must have direct access to the highest level of management and has the function of providing a link between the provider and the pilot on board.
- The SMS must be periodically evaluated, and if necessary revised in accordance with documented procedures. Results of reviews and audits must be brought to the attention of all personnel in the area involved, and the provider must take timely corrective action on deficiencies found.
- A Check Pilot must be appointed, as part of a continuous improvement process, to observe and make recommendations on individual pilots. The first item on the checklist for Check Pilots is an assessment of the fatigue status of the pilot at the start of pilotage and initial passage planning. All checklists must be signed and submitted to the Australian Maritime Safety Authority.

In September 2008, Queensland Health introduced a mandatory requirement for every regional health unit to develop a local FRMS covering doctors and allied health professionals (with negotiations in progress to incorporate nurses as well; Drew Dawson, personal communication).

5. Strengths and weakness of FRMS

5.1. Perceived strengths of FRMS

Fatigue risk management systems aim to limit the exposure of transportation workers to all of the causes of fatigue, namely:

- the length of time awake that is required for work;
- the duration of continuous time on task;
- the daily cycle of the circadian biological clock; and
- fatigue across the duty cycle.

FRMS go beyond simply managing the fatigue levels of transport operators (the focus of HoS regulations). FRMS also seek to address the safety risk that fatigued operators represent. Consistent with current understanding of accident aetiology, FRMS include multiple defensive strategies to minimize the risk that fatigued workers represent to themselves and others in the work environment (Dawson and McCulloch, 2005).

FRMS are also consistent with the philosophy of the Robens Report (Robens, 1972) and modern OSH legislation, in that they permit responsible operators to self-regulate on the basis that "those that create the risk are best placed to manage it". They shift the focus of responsibility from regulators towards employers and employees.

In principle, FRMS provide a flexible, proactive risk management approach adapted to the specific operational context, rather than the HoS approach of forcing all operations into a one-size-fits–all regulatory framework. The exercise of developing a safety case to put to the regulator for accreditation of an FRMS requires consideration of fatigue risk in a broader safety systems context, rather than the isolation of fatigue as a hazard that is implicit in HoS regulations.

It is argued that FRMS can provide competitive advantage by enabling a company to undertake particular operations in a more flexible and profitable way, for example enabling drivers to complete a return trip rather than having to stop overnight in a location within an hour's drive from home. The low cost air carrier EasyJet has successfully argued for substantial reductions in insurance premiums through having an effective FRMS in place (Stewart, 2007).

5.2. Perceived weaknesses and implementation challenges for FRMS

5.2.1. Fatigue versus safety

A better understanding of the complex relationship between fatigue and safety is needed to improve the implementation of FRMS (see Williamson et al., 2011). Historically, fatigue research has been dominated by laboratory studies using simple tests to measure performance. However, recent industry-based research suggests that the relationship between fatigue and safety may not be linear (Folkard and Akerstedt, 2004). Risk is not necessarily greatest when fatigue levels are highest, but may in some cases be greater at intermediate fatigue levels where the operator tends to pay less attention to her/his performance.

The link is even more complex in ultra-safe systems such as aviation. For example, the large simulation study of Thomas et al. (2006) demonstrated that fatigue induces a shift in the error profile and error management of flight crew. This highlights the need for further research on the effects of fatigue on complex decision making.

These complexities also indicate that implementation of FRMS could be improved by better integration with the latest developments in safety science, such as the resilience engineering approach (Hollnagel et al., 2006). New operational tools are being developed, for example the Functional Resonance Accident Model (FRAM), which aims to support risk analysis or accident analysis by looking at the combined effects of normal variability in system functions (Hollnagel, 2004). From an FRMS perspective, these new approaches may provide more reliable methods to identify the conditions and contexts where operator fatigue can jeopardize safety.

5.2.2. Knowledge base

Arguably the Achilles heel of FRMS is the need for regulators, employers and employees to have an understanding of the causes and consequences of fatigue that is sufficiently in-depth for them to meet their responsibilities in relation to FRMS.

- Traditionally, transport regulation agencies (and agencies responsible for implementing OSH legislation) have greater expertise and experience in managing physical hazards rather than hazards arising from human factors. They may have limited in-house expertise to accredit and audit complex fatigue manage-

[9] The function of a pilot on board a ship is to provide information and advice to the master to assist safe passage through the pilotage area, although the master remains responsible for the vessel.

ment systems (A lack of in-house expertise is also an issue for the development of HoS regulations and the approval of variations or exemptions from them).
- Developing a safety case for FRMS requires considerable knowledge and commitment of resources on the part of a company.
- FRMS requires employers and labour representatives to have a clear understanding of the causes and consequences of fatigue in order to move the debate out of the industrial arena and into the safety arena.
- Individual employees need to have a clear understanding of the causes and consequences of fatigue in order to manage their own work/life balance and contribute constructively to their company's FRMS.

While the scientific knowledge base to support FRMS is robust and expanding, translation of this knowledge into usable resources for regulators, employers, and employees remains an information bottleneck. There is a great need for accredited, competency-based education and training programmes across all sectors.

In the USA, a cross-government effort lead by the Department of Transportation has identified a particular need for developing a credential for work schedule managers. A current initiative is undertaking a job analysis for these types of positions, capturing the various work tasks and the knowledge, skills and abilities required. The views of academics and experts in the field of work scheduling and shift work research are being contrasted with those of people currently employed in positions with responsibilities for staffing, scheduling and generally managing work schedule operations. Analyses will identify commonalities and differences between the views of the groups, to inform the development of training requirements and tools necessary for the certification of work schedule managers.

Evaluation of the effectiveness of training is a neglected area. An evaluation of fatigue management education programmes for light and heavy vehicle drivers working for a major oil company (Gander et al., 2005a,b) found significant improvement in knowledge immediately after a 2-h live training session, which was still evident 1–26 months after training. At follow-up, the great majority of both groups rated their training as at least moderately useful and about half reported changing their fatigue management strategies at home as a result of training, and half reported changing their strategies at work. It was concluded that fatigue management education is useful for developing a fatigue management culture within an organization. In contrast, in a lecture to the Parliamentary Advisory Council for Transport Safety (PACTS), Folkard (1999) reported unpublished data showing that the counselling of shift workers is initially effective, but that any improvements are no longer apparent after 6 months. This difference may be due in part to the commitment of the oil company to ongoing activities to maintain fatigue awareness, for example poster campaigns, discussions at 6-monthly driver forums, key-rings, and a napping kit (containing a napping procedure card, a neck pillow, an alarm clock, and a water bottle) given to employees as a Christmas gift.

FRMS is arguably becoming a niche market for consultants, and the quality (and cost) of advice available to regulators and industry is uneven. Companies introducing FRMS can feel exposed and unsure as to whether collectively the systems they are introducing are sufficiently robust. Departing from the perceived safety of the HoS regulations requires them to develop systems to manage their fatigue risk, balancing this with business pressures and the desires of their workforce. The quality of the "expert" advice they are able to access can be critical.

5.2.3. Challenges for regulators

Among transport regulators considering FRMS, most appear to be introducing it as an alternative means of compliance, not as a blanket substitute for HoS regulations. In addition, some jurisdictions are considering a staged approach to full FRMS (see below). Having two or more compliance alternatives running in parallel may place considerable extra demands on regulators and enforcement agencies. Regulators also need to provide clear, practical guidance material for the successful implementation of FRMS.

A high level of regulatory support and involvement is likely to be necessary in some sectors when FRMS is introduced as an option. For example, two attempted implementations of FRMS in the trucking industry (in Queensland and New Zealand) have experienced major delays at the stage of accrediting each company's FRMS proposal, which involves an iterative process between the company and the regulator (Burgess-Limerick and Bowen-Rotsaert, 2002; Denton, 2007). In small regulatory agencies with limited numbers of suitably qualified staff, there is a potential conflict of interest for staff who work closely with a company to develop and accredit its FRMS and then take on the role of auditing that FRMS once it is implemented.

Another challenge for regulators is the widespread use of subcontracting in some industries, notably trucking. Mechanisms are needed to ensure that the parent company's FRMS is implemented amongst sub-contractors.

5.2.4. Enforcement

FRMS may complicate enforcement. For example, in the trucking industry FRMS can create significant challenges for a policeman who stops a vehicle on the side of the road to check whether a driver is compliant with his/her company's FRMS. In some situations, it may be appropriate to have a tiered enforcement regime, with less significant infringements dealt with under the internal and external FRMS auditing processes, and more significant infringements dealt with by the police or other external enforcement agencies such as OSH inspectors. This may require changes to other legislation under which the current enforcement agencies operate. The appropriate balance of internal and external enforcement regimes will be a critical factor in preventing the potential abuse of FRMS as de facto deregulation.

On the other hand, including the transport sector under the coverage of the general occupational health and safety legislation can offer additional avenues for enforcement. For example, when the coverage of the New Zealand OSH legislation was extended, officers of the specialised branch of the Police that deals with heavy transport safety (the Commercial Vehicle Investigation Unit) were trained as OSH inspectors, which gave them wider powers to search vehicles as workplaces and to access company records, than were permitted under the Land Transport Act. In 2008, the first case for prosecution of a trucking company under the OSH legislation occurred, for failure to provide safe systems of work (Crown versus Bushetts Transport Ltd.). This illustrates the usefulness of the duty of care requirements in the OSH legislation, which enable an important move away from the prosecution of individual drivers for breaches of the HoS regulations, to the examination of the organizational practises that systematically exacerbate the risk of driver fatigue.

5.2.5. Cost

There is a concern that FRMS increases compliance costs, effectively shifting the regulatory cost from the government to the operators. A related concern from an industry perspective is the lack of effective regulatory support for companies trying to develop their own FRMS.

At the regulatory level, implementation of FRMS may requires re-evaluation of the incentives and penalties designed to encourage safe behaviour in an industry. At the company level, the perception of increased compliance costs may be able to be addressed by a more comprehensive analysis of the costs of FRMS, balanced against safety gains and reduced insurance premiums.

5.2.6. Business size and complexity

The costs of developing a safety case and implementing and running an FRMS may be prohibitive for some smaller operators, which could be seen as inequitable if FRMS gives larger companies a competitive edge. This may be less of an issue in industries that already have safety case regimes to identify and manage their organization/operational risks, and for whom the introduction of FRMS is a natural progression.

This is the basis of the approach taken in the New Zealand maritime sector. Instead of introducing HoS limits, the regulator chose to assist the sector to develop fatigue risk management programmes that build on an existing safety management system required for the certification of all commercial vessels, known as the Safe Ship Management Programme (Wayne Perkins, MNZ, personal communication). A range of advisory materials has been developed that are tailored to the needs of different sectors (fishing boats, harbour ferries, work boats, and charter boats), and additional sector guides are planned. Working through the appropriate guidance booklet enables an operator to meet the requirements for an FRMS for his/her particular type of operation. A unique feature of this approach is that the regulator provides detailed guidance on the level of complexity that is required, down to the level of a two-person operation. This innovative regulatory programme is currently on hold, pending a review of the Safe Ship Management Programme.

A recent survey of the knowledge and practise of fatigue risk management among air transport operators in New Zealand (55% response rate) provides rare insights into the issue of company size (Signal et al., 2008). The 88 companies that responded were classified according to the regulatory category they operated under, with some operating under multiple categories (large aircraft operator $n = 10$; medium aircraft operator $n = 10$; small aircraft operator $n = 77$). The majority of small aircraft operators complied with the prescriptive flight and duty time limits, and only 10 had an FRMS or other accredited scheme. Equal numbers of medium and large aircraft operators complied with the prescriptive flight and duty time limits or had an FRMS or other accredited scheme.

There were no differences found between organizations operating under the flight and duty time limits and those using a company-specific scheme, on ratings of how well fatigue was managed, the number of fatigue management strategies employed (from a list given in the questionnaire), or the frequency of use of selected strategies. However, as expected, larger operators had a more comprehensive range of fatigue management strategies in place, based on formal processes, while smaller organizations had fewer and less formal strategies, primarily based on personal contact. This is consistent with the greater resources available in larger organizations, and with the fact that their operations were generally more complex than those of the smaller operators.

The study also compared the views of a manager, a line pilot, and a person with responsibility for scheduling in each organization (in some small organizations, all three roles were the responsibility of one individual). Within the same organization, managers were more likely than line pilots to report the use of specific fatigue management strategies. It is questionable whether strategies can be effective if operational staff is unaware of them. Overall, the study concluded that the availability of more flexible regulatory options since 1995 had not greatly changed fatigue management practices, and that there was a need to raise the level of knowledge within the industry regarding the causes and consequences of fatigue and strategies for its management.

5.2.7. FRMS evaluation

Another important challenge for the implementation of FRMS is the evaluation of their effectiveness in reducing the risk of operator fatigue and mitigating its negative impact on safety. This challenge also applies more broadly to safety management systems (Transport Canada, 2007) and to HoS regimes, under which organizations can be compliant and yet still be unsafe (Benner, 1984).

Self-evaluation is an intrinsic feature of FRMS that helps an organization to learn, and to develop its own safety management strategies in a changing environment. Regulatory accreditation of an FRMS, and subsequent audit once it is operational, provide opportunities for external evaluation. The choice of indicators for evaluation is important, particularly in maintaining an appropriate balance between the potentially competing goals of FRMS, namely reducing fatigue and improving productivity.

Ideally, the effectiveness of FRMS would be evaluated against non-FRMS management of fatigue in similar operations. Recent experience in the New Zealand road transport industry offers some lessons for this type of evaluation. The regulator embarked on a trial in 2000 to develop and evaluate FRMS as a regulatory alternative to HoS regulations (Denton, 2007; Gander et al., 2008). The intention was to run the FRMS trial for about 18 months and to recruit 200 drivers from 12 companies nationwide, half of whom would move into operations covered by their company's FRMS, and half of whom would serve as controls and continue to work within the HoS limits.

In practice, the process of accrediting each company's FRMS took much longer than anticipated and was an important learning experience for both the companies and the regulator. The development of appropriate documentation for FRMS drivers to carry for enforcement purposes was also time-consuming. The FRMS trial was eventually overtaken by changes in the HoS regime, which came into force on October 1, 2007. A new process for applying for variations to the HoS regime reduced the attractiveness of the FRMS approach for some of the companies participating in the trial. In addition, there had already been a high turnover of drivers who had participated in the baseline survey of the FRMS companies, which was undertaken before each company had their FRMS accredited. Consequently, in November 2007 the regulator decided to discontinue the scientific evaluation of the FRMS Trial, although a small number of companies have chosen to continue with implementing FRMS.

6. Discussion

A broad range of operational factors can affect successful fatigue risk management. They differ according to the regulatory framework(s) under which an organization operates, the complexity, scale, and nature of its operations, the operational reliability required, and the particular demographics of its workforce. For the FRMS approach, understanding of the effects of operational factors will increase as implementation expands.

6.1. Regulatory approaches

Most, but not all, of the regulatory frameworks with which we are familiar include both HoS and FRMS as alternative means of compliance. Arguably, some types of operations can be conducted safely and profitably within the HoS limits, and not all companies will have the need or the resources to implement more complex FRMS. On the other hand, some of the strategies normally required in FRMS may also increase safety in operations complying with HoS, for example education and training for relevant staff, systems for ongoing monitoring of fatigue levels, and systematic analysis of the role of fatigue in safety incidents and accidents.

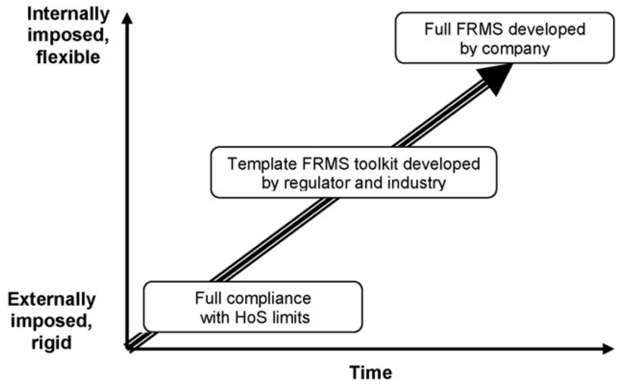

Fig. 3. A hybrid regulatory model for FRMS.

There can also be stages between compliance entirely based on the HoS regulations and compliance by full FRMS (for example the Basic and Advanced Fatigue Management regimes in the new Australian National Heavy Vehicle Accreditation Scheme). A related concept is allowing operators to step progressively further outside the HoS limits as they demonstrate that they can implement risk mitigation strategies to manage smaller excursions. Fig. 3 describes an example of this type of hybrid regulatory framework (after Drew Dawson, with permission).

Having alternative means of compliance gives regulators the option to require a company that fails to achieve the necessary standards in a more flexible regime to default back to the rigid HoS regime (while problems are remedied, or permanently), rather than being required to cease operating.

6.2. The way forward

To help visualize the way forward for fatigue risk management in general and the FRMS approach in particular, we would propose that fatigue risk management in 20 years time will have the following features.

- A range of regulatory options are available that meet the needs of different types of companies, commensurate with the complexity, scale, and nature of their operations and the level of reliability required.
- Competency-based training is required for regulators, managers, and employees to ensure they have a level of knowledge adequate to meet their respective responsibilities in FRMS or other approaches to fatigue risk management.
- The role of fatigue in all safety events is analyzed routinely and reliably.
- De-identified safety data collected as part of each company's FRMS are routinely compiled across each industry sector, providing sufficient data for the analysis of trends in safety events that are relatively rare in any one organization. This will include events that fall below the severity threshold for mandatory reporting.
- Appropriate performance indicators are routinely tracked in companies, and the costs and benefits of FRMS are clear and widely understood.
- Effective fatigue risk management (achieved through a range of approaches) is universal in the transport sector and delivers demonstrable improvement in safety, productivity, health and well being.

Ideally, in 20 years time the FRMS approach will have revitalized the spirit and mission of the original Factories Acts. It will use advances in scientific knowledge to improve safety while respecting human physiological limitations, and facilitate healthy work/life balance through explicit acknowledgement that there is more to life than work and sleep.

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