Fatigue and its contribution to railway incidents

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I SPECIAL TOPIC REPORT

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Executive summary

Introduction

Fatigue presents a serious risk to operations in the rail industry. A key driver for writing this special topic report was a recommendation from the Rail Accident Investigation Branch (RAIB) resulting from the Shap (uncontrolled run-back) incident in 2010. The recommendation was that RSSB should implement measures to improve the quality and quantity of available data relating to fatigue-related railway accidents and incidents. This report aims to provide data on the role of fatigue in incidents and summarise the types of data on fatigue currently available.

Methods

Available data from the Incident Factor Classification System (IFCS) database has been analysed for 246 high risk railway incidents. Initially data was analysed to understand the contribution of fatigue to the incidents. In addition, data from the Safety Management Information System (SMIS) for these 246 incidents has been reviewed. Data entry statistics have also been calculated to understand how often data is being recorded and entered into various fields that may help identify fatigue and consequently assist with tackling future risks presented by fatigue.

Results

The results have provided a new insight into the prevalence of fatigue in rail incidents and established a good basis for fatigue analysis. For the incident sample, the results showed that:

- IFCS analysis identified fatigue as a factor in 21 % of the incidents; however, the relevant check box in SMIS was only marked for 1 % of incidents.
- Home-life related fatigue was the most cited reason for the fatigue (40 %) followed by work-related fatigue (38 %).Train drivers were most affected by work-related fatigue rather than home-life related fatigue.
- Relevant fields for fatigue are often not completed in SMIS. For example, information regarding the individual's roster pattern, sleep duration, and commute time is not identified and recorded in the database.

- Fatigue data is entered more often for train drivers than any other job role with a focus on SPAD incidents.
- Where Fatigue Index (FI) scores are calculated there are a number of issues:
  - FI is used to calculate a value for the average fatigue level over a roster pattern rather than an individual shift.
  - Outdated versions of the FI tool are being used (identified by ORR) and therefore we could not use this data reliably in this report.
  - There is an over-reliance on FI outputs to make a decision about fitness for duty during the roster process, at the time of an incident, or during an accident investigation.

Conclusions

This is the first time that data in the IFCS has been used for analysis. The data has shown that fatigue affects individuals at work in the rail industry in various ways. It is therefore necessary that we continue to investigate incidents and where possible identify where fatigue has been a contributing factor. This will enable rail companies to inform their Fatigue Risk Management Systems (FRMS) in an attempt to minimise fatigue experienced by front line staff which may lead to an incident.

Recommendations

The following recommendations have been made:

1. Continue to review incidents using the IFCS approach to identify fatigue and associated underlying causes. The continual development of a wider sample of incidents which will be updated on a regular basis will support the management of both fatigue and other incident underlying causes. - Action for RSSB's Human Factors (HF) team.
2. Review the IFCS database sub-categories to allow incidents to be better categorised for fatigue - Action for RSSB's HF team.
3. In the short term to encourage the completion of non-mandatory fields in SMIS, so when necessary, analysis can be made with as complete a data-set as possible. This includes fields related to factors such as roster pattern, sleep duration, and commute time. - Action for RSSB's Data and Risk Strategy Group (DRSG).
   a. Long-term action to make these fields mandatory by agreement with the industry - Action: RSSB's System Safety Team to develop proposals for consultation as part of the next update of RGS GE/RT8047.

4 Industry to improve the quality of fatigue assessment and reporting in incident investigations. This can be improved by the provision of better guidance on how to investigate fatigue within wider proposals related to human factors and investigations. - This action has been agreed with DRSG.

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1 Introduction

1.1 Purpose

The rail industry recognises the importance of fatigue and is continually striving to improve the management of fatigue within the workforce. Recently, within RSSB, the System Safety Risk Group (SSRG) have collated all the work completed to date related to fatigue into a single report. This highlights that, as well as the wealth of knowledge and guidance available surrounding managing fatigue, over the past 10 years there has been 4 major research projects focussed on the topic:

1 T024: Driver vigilance devices - systems review

2 T059: Human factors study of fatigue and shift work

3 T699: Fatigue and shift work for freight locomotive drivers and contract drivers

4 T997: Managing occupational road risk associated with road vehicle driver fatigue

This report aims to support the industry understanding of the contribution of fatigue to incidents. A key driver for this work is the following recommendation from the Rail Accident Investigation Branch (RAIB) report on the 2010 Shap (uncontrolled run-back) incident:

> *'RSSB should implement measures to improve the quality and quantity of available data relating to fatigue-related railway accidents and incidents. Options for consideration should include an enhancement of the Safety Management Information System (SMIS) to provide more accurate reporting of fatigue-related events.'*

This recommendation was made because RAIB noted that between the years 2000 and 2010 there had only been 111 fatigue-related incidents reported. They believed it was likely that fatigue-related incidents were being under-reported and instead attributed to other factors such as driver error, equipment failure and inattention. Further to this, RAIB found the SMIS database did not identify all fatigue-related incidents because fatigue was not stated as a factor when data were entered. On comparison with their own data RAIB found 21 fatigue-related events missing, prompting the recommendation to enhance the industry database to allow improved reporting and analysis of data.

1.1.1 Intended audience

This report has been designed to meet the need of the RAIB recommendation, but fundamentally the report is for the industry to:

- Add to the body of knowledge around fatigue.
- Highlight the benefits that can be derived and further developed from the use of the IFCS module and the recording of fatigue information in SMIS.

This report will be of interest to safety and risk specialists, those reporting into SMIS and other safety management systems, driver managers, and occupational health specialists.

1.2 Report scope

This RSSB special topic report reviews and presents an analysis of fatigue-related incidents from a sample of railway incidents. In doing so, the aim is to show the importance of managing workforce fatigue, identify any trends in fatigue-related incidents and provide an understanding of why accurate reporting and data capture is necessary to support reduction in the likelihood of fatigue-related incidents occurring.

1.3 Data

Unless otherwise stated, the data used in the report comes from the industry's Safety Management Information System (SMIS) and the Incident Factor Classification System (IFCS). SMIS is a database where the details of all safety events in the rail industry are entered. RSSB then validates this data and analyses it in various ways to help the industry assess risk and safety performance. One method of analysis is the use of the IFCS which forms a module of SMIS. A risk-based sample of the incidents recorded in SMIS are analysed by human factors specialists at RSSB using the IFCS. The IFCS aims to provide more detailed information to the GB rail industry by building a database that summarises and classifies the factors associated with incidents.

The sample of incidents included in the IFCS is based on high risk railway incidents. The sample aims to include:

- Potentially high risk train accidents
- Irregular working incidents risk ranked as potentially severe

- Cat A SPADs risk ranked 20+[1]
- Workforce fatalities including work-related road traffic collisions
- Falls from height
- Workforce struck by train
- Passenger fatal or major injury whilst boarding or alighting
- All RAIB investigations

A requirement for inclusion in the IFCS database analysis is the availability of investigation reports. The data sample is therefore limited by the investigation reports that have been made available by industry. The data currently available in the IFCS comes primarily from 2011 and 2012. Data from 2013 and 2014 are currently being added to the database.

1 The SPAD risk ranking tool is used to calculate SPAD risk for each SPAD. It takes into account a range of factors (such as the length of overrun and type of conflict). This results in the calculation of a score between 0 and 28, with 0 representing a SPAD with negligible risk, and 28 a SPAD with a significant potential to result in a multi-fatality accident.

2 What is fatigue?

2.1 Definition and symptoms

Fatigue can be comprised of mental and/or physical elements, however, in the rail industry we are particularly concerned with mental fatigue.

Due to its complexity, there is no single, agreed, scientific definition of mental fatigue. The Office of Rail Regulation (2012) defines it as *'a state of perceived weariness that can result from prolonged working, heavy workload, insufficient rest or inadequate sleep'*. A similar definition is given in Managing Fatigue: A good practice guide (RSSB, 2012) but in addition, this document also adds that fatigue can be 'a feeling of extreme tiredness and being unable to perform work effectively.'

It is important that persons involved in safety critical operations such as train drivers, signallers and maintenance staff are not fatigued as this will increase the likelihood of incidents and accidents occurring. Appendix A provides a short review of some key fatigue literature.

2.2 What causes fatigue?

Fatigue can be caused by one or the sum of a number of contributing factors. A common factor is inadequate rest and sleep caused by a reduction in sleep duration, extended waking hours or a disruption in the timing of sleep-wake periods. However fatigue can also be influenced by factors external to rest and sleep such as workload, the individual's interest in the task or their motivations associated with the task.

There are 3 main agreed groups of factors that cause fatigue (ORR - Managing Rail Staff Fatigue, 2012):

1 Work related factors; such as timing of working and resting periods, length and number of consecutive work duties, intensity of work demands.

2 Individual factors; such as lifestyle, age, diet, medical conditions, drug and alcohol use, which can all affect the duration and quality of sleep.

3 Environmental factors such as family circumstances and domestic responsibilities, adequacy of the sleeping environment.

2.3 The consequences of working while fatigued

The consequences of working while fatigued can be significant. Many of the world's major accidents started late at night or in the early hours of the morning such as at the nuclear power plants in Three Mile Island and Chernobyl or the chemical plant at Bhopal all of which have been directly related to fatigue (Moore-Ede, 1992).

A fatigued individual will be less alert, less able to process information, will take longer to react and make decisions and will have less interest in working compared to a person who is not fatigued. Fatigue therefore increases the likelihood of an individual making errors and adversely affects task performance especially in tasks requiring:

- Vigilance and monitoring
- Decision making
- Awareness
- Fast reaction time
- Tracking ability
- Memory

These negative effects of fatigue contributed to the following high profile incidents investigated by RAIB over the past 10 years:

- Derailment of a freight train at Brentingby Junction, near Melton Mowbray, 9 February 2006.
- Freight train collision at Leigh-on-Sea, 26 April 2008.
- Derailment of 2 locomotives at East Somerset Junction, 10 November 2008.
- Uncontrolled freight train run-back between Shap and Tebay, 17 August 2010.

The severity of these incidents and the fact that fatigue was the main contributor to the occurrence of each puts the importance of fatigue into context.

It is important to remember that fatigue does not only affect the rail industry through events on the railway but also increases road driving fatigue. There are likely to be at least 75,000 road vehicles linked to the rail industry used by mobile operations managers, maintenance teams and contractors. Staff may need to travel from job-to-job early in the day or late at night, depending on

the task in hand, and to access very particular bits of the infrastructure, depending on engineering schedules and incidents that occur (RSSB).

2.4 Management of fatigue

2.4.1 Reactive management of fatigue

For an individual experiencing extreme tiredness, there are a number of methods or reactive countermeasures they may apply in an attempt to remain awake. These include: napping, taking short breaks, ingestion of caffeine, altering the environment (light, temperature, and sound) and many more (Caldwell et al., 2009). However, train drivers may choose (or feel they have no choice but) to simply ignore any indicators of sleepiness as they are not afforded the opportunity, as road drivers are, to stop at a service station for a power-nap to restore some alertness. The culture of an organisation may also influence the likelihood of staff feeling able to raise concerns that they feel, or may become, fatigued during their shift for fear of reprisal. To balance that, train drivers may willingly continue to drive in a fatigued state because evidence has shown that as humans we are not good at judging or identifying when we are likely to fall asleep (Kaplan et al., 2007).

There are numerous strategies available to manage fatigue, many of which were developed in reaction to fatigue-related disasters. For example as a result of the Hidden inquiry into the Clapham Junction accident (1988) the 'Hidden limits' on working time were introduced to address management failures surrounding working hours, overtime and fatigue. However, these limits were generic and did not address all the known causes of fatigue. Basic management methods (such as complying with prescriptive limits) are not optimal because they do not take into account major influences on fatigue such as home-life activities, the type and difficulty of the task or any health factors that may influence the individual's fatigue. The Energy Institute (2014) found that where basic fatigue management methods were used, these controls were often sporadically applied and disconnected. Therefore, there is the need for organisations to proactively manage the fatigue of their workforce effectively using a more formal management system especially in safety critical work.

2.4.2 Proactive management of fatigue

Many industries have adopted the use of Fatigue Risk Management Systems (FRMS) with an aim to identify, monitor and manage the risks associated with fatigue and implement the preventative and protective measures needed to

control these risks. The use of FRMSs ensures that as far as reasonably practicable employees are performing with an adequate level of alertness.

In 2010 the Department for Transport (DfT) conducted a study (DfT RR120. 2010, p29) which reported several advantages of adopting a FRMS approach to managing fatigue including improved safety, improved staff morale, reduced absenteeism, and future-proofing against any changes in legislation. By adopting a FRMS approach the organisation introduces several layers of defence to prevent fatigue and fatigue-induced errors from developing into incidents or accidents. A good FRMS should include controls such as staff selection procedures (taking into account medical conditions which may contribute to fatigue), limits on working hours and patterns and a good system in place for staff and managers to know what to do in a situation where a staff member feels or appears too tired to work safely.

To assist with implementing these FRMS components there is literature and legislation that highlights minimum standards and good practice that should be followed (ORR 2012, RSSB 2012). The ORR (2012) provide controllers of safety critical work with 'The ROGS Nine-Stage Approach' to be used to establish effective arrangements for managing the risks arising from safety critical workers:

1 Identifying safety critical workers affected.

2 Setting standards and designing working patterns.

3 Limiting exceedances.

4 Consulting with safety critical workers.

5 Recording the arrangements.

6 Providing information to safety critical workers.

7 Monitoring.

8 Taking action when safety critical workers are fatigued.

9 Reviewing the arrangements.

In recognition of a need for further guidance on specific aspects of fatigue risk management, ORR has asked that RSSB produce guidance on tools which use biomathematical models to predict fatigue risk from roster patterns, and also guidance for individuals and companies on managing fatigue risk during first night shifts. RSSB is currently considering research in these areas.

2.5 HSE fatigue and risk indices

In 1999 the HSE Fatigue Index (FI) was created to assess the risks from fatigue associated with rotating shift patterns (Rogers et al., 1999). This index was derived from 6 factors associated with fatigue, namely length of shift, interval between shifts, number of rest days, quality of rest breaks, variability of shifts, and time of day. The output provided one result and gave an indication of the likelihood a person would feel fatigued. This tool was used to assess an employee's current working pattern and compare a new proposed pattern to see which scored lower and had less risk of fatigue.

A report by the Health and Safety Executive (Spencer et al., 2006) describes research that has been carried out to update the original HSE Fatigue Index. The changes to the Fatigue Index incorporated more recent information on cumulative fatigue, time of day, shift length, breaks and recovery from a sequence of shifts. A review of risks related to shift work was also carried out, enabling the specification of two separate indices, one related to fatigue (the FI) and the other to risk (the Risk Index (RI)). The main differences between these concern the different trends in relation to time of day in fatigue and risk. The FR and RI indices are thought to be the most widely used biomathematical model to predict fatigue in the GB rail industry and there is an Excel spreadsheet calculator for assessing shift patterns which is available on the HSE website. This allows the user to obtain an indication of the fatigue and risk associated with a specified pattern of work. This is sometimes referred to in incident investigations as the 'Fatigue Calculator' or the 'FRI Calculator'.

2.5.1 Interpretation of FI and RI scores

The latest FRI output provides a single number for the FI and another number for the RI.

For FI, the output value will be between 0-100 and indicates the percentage of individuals who if exposed to the input shift schedule will experience high levels of fatigue. For instance taking a result of 30, this would indicate that there was a 30 % chance that employees would be experiencing high levels of fatigue and would struggle to stay awake during the particular shift. It is important to understand that there is not a threshold, cut-off or black and white divide between what is an acceptable fatigue score and what is not. Research by The Health and Safety Laboratory (HSL) and ORR (2008) found that the majority of working patterns at the time scored less than 30-35 for day shifts and 40-45 for night shifts. These figures have frequently been used

as guideline thresholds not to exceed. However, organisations should not assume that just because their FI analysis of working patterns returns a result below the 2008 'indicative thresholds' that they need not do more. Emphasis must be put on the need to reduce the FI scores to a value as low as reasonably practical to further mitigate the risks presented by fatigue.

For RI, a comparison between 2 shifts is made. A base shift pattern is allocated a score of 1 and is based on the average level of risk of accident or error attained in studies on people working 12 hour shifts on a 2 day, 2 night, and 4 rest day schedule in the rail sector. Consequently, a risk score of 2 would indicate the risk of a fatigue-related incident occurring to be double in the analysed shift pattern. To use RI values effectively, organisations need to determine the level of risk that they would consider acceptable based on the type of work being done and the individuals doing it. For example, a high risk score might be considered acceptable by an organisation if the work is low risk and is undertaken by highly competent and experienced workers. Alternatively, if the work is safety critical or hazardous, or undertaken by less competent or inexperienced workers then an organisation may decide that risk scores above a certain level are unacceptable for that particular type of work or particular groups or workers.

2.5.2 Limitations to using the Fatigue and Risk indices and other biomathematical models

While the FRI tool is beneficial for designing shift patterns that will not induce excessive fatigue it should be used with caution because biomathematical models are usually based on group data whereas each individual is unique and will have different fatigue thresholds or be able to tolerate fatigue differently. Another issue with biomathematical models is that they do not take into account personal differences such as age, stress, health, and quality of sleep; nor do they account for factors in the work environment that may have an impact on fatigue such exposure to heat.

There are a number of these biomathematical models available, in addition to the HSE FRI tool, and some discussion around their use can be found in Appendix C.

3 Analysis methods

All data was extracted from the SMIS and IFCS databases into a Microsoft Excel Spreadsheet. Simple analysis methods in Excel (such as PivotTables) were used allowing us to detect patterns, relationships and discover trends in the data.

3.1 IFCS search for fatigue-related incidents and analysis

To analyse the impact of fatigue on railway incidents, data held in the IFCS database from 2011 onwards for GB rail has been investigated. A total of 246 reports were available for analysis. Within the 246 reports there was a variety of incident types including collisions, derailments, near misses and SPADs (Table 1).

Table 1 - Breakdown of full sample by incident type

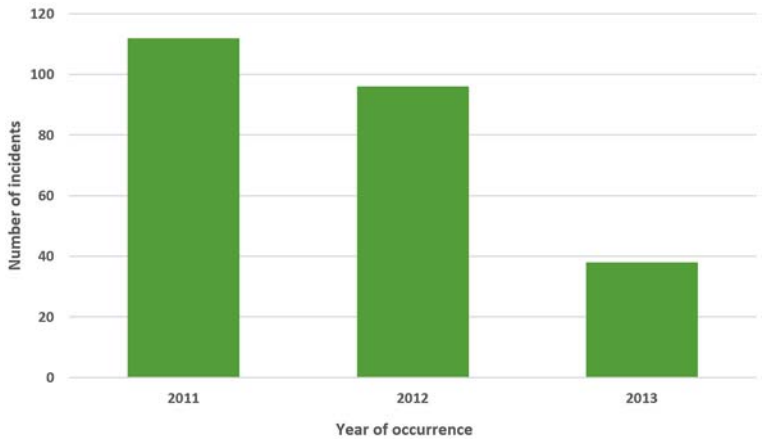
Incident Type	Total
Collision	10
Collision with object	5
Collision with third party	6
Derailment	24
Infrastructure damage	2
Infrastructure failure	3
Near miss	13
Operating irregularity	41
Passenger harm (movement)	4
Road traffic collision	3

Table 1 - Breakdown of full sample by incident type

Incident Type	Total
Runaway	1
SPAD	130
Vehicle malfunction	2
Workforce harm (non-movement)	2
Grand total	**246**

Due to the availability of reviewed incident reports the majority of incidents included in this report are from 2011 and 2012 (Figure 1). Incident reports from 2013 and 2014 are currently gradually being added to the IFCS database.

Figure 1 - Breakdown of incident sample (N=246) by year



For classifying incidents the IFCS has two main factor types: human error and management/system failures. All management and system errors are classified using Network Rail's 10 incident factors, which are defined in Table 2.

Table 2 - Network Rail's 10 incident factors

Incident factors	Definitions
1 Communications	Concerned with verbal communication only - How we relay information to each other in the context of safety critical information. This includes people not communicating information or not reaching a clear understanding when they are communicating.
2 Practices and processes	The rules, standards, processes and methods of working which guide and structure how certain activities are undertaken on the railway including: the operational rule book, technical standards and safe systems of work.
3 Information	The information used to support an activity e.g. late notices, electrification/isolation diagrams and signage. Information must be relevant and timely.
4 Workload	Understanding the demand created by particular activities. Demand is created by the task (number and combination of tasks), the context (how and where and urgency of tasks) and the individual (skills, experience and perception of work).
5 Equipment	Any equipment that is used to undertake or support an activity and can be a factor if it is not being used as intended, if it is faulty, if its design is not compatible with its use or if the layout is not in the order in which it is used.
6 Knowledge, skills and experience	Can be a factor in an accident/incident if the individual(s) involved did not have the appropriate knowledge to perform safely or if they were not familiar with the circumstances in which they found themselves.

Table 2 - Network Rail's 10 incident factors

Incident factors	Definitions
7 Supervision and management	Can be an underlying reason for an accident or incident because of the decisions they make about resources, budgets, work allocation and planning. They can also have a more direct impact through the example they set and the monitoring and assessment processes they have responsibility for.
8 Work Environment	Contains environmental stressors such as lighting levels, noise, temperature and vibrations that can lead to feelings of discomfort or act as distractions, impacting on an individual's performance.
9 Personal	Refers to a collection or influences that may affect the individual and in particular that individual's ability to maintain attention and focus whilst at work. They are concerned with fatigue, physical and mental wellbeing and the individual's state of attention.
10 Teamwork	Concerned with how we work together and coordinate to achieve safe performance. Factors that influence team working include: the number of people in the team, team structure, team stability and team leadership.

Incidents with factors relating to fatigue are primarily classified at the highest level under 'Personal'. This category refers to a collection of influences that may affect the individual and in particular that individual's ability to maintain attention and focus at work including fatigue, mental and physical wellbeing and state of attention. Within this category two types of fatigue are distinguished: Home-related fatigue and Work-related fatigue. However there are many other factors that may influence or arise due to fatigue. For the purpose of this report the sample data has been reviewed and reclassified to ensure where possible that all fatigue-related incidents have been identified. In particular, the category ill-health has been reviewed to identify where this has led to the individual being fatigued as this currently is captured separately.

When searching for fatigue-related incidents in the sample data a number of processes were carried out to ensure data was not missed. Searches were undertaken using the fatigue classifications contained in the database. Further searches on keywords such as fatigue, sleep, and tired were undertaken and a further validation of the returned results to ensure the result had the keywords used in the correct context (for example, to exclude searches which returned results relating to sleepers and fatigue in the engineering sense of the word).

3.2 SMIS data review

To review data held in the SMIS database, the same incidents analysed from the IFCS database were used. This provided a sample of 246 incidents and all fields under 'person workforce details' were requested for review as well as fields in the cause summary relating to fatigue. For incidents where there was more than one person involved, the person with main involvement was selected for review. To review this data, various checks and analysis were conducted to identify the frequency of data entry into fields, investigation into different circumstances where data is entered and a review of the accuracy of the data.

3.3 FRI data review

FRI data are included in the IFCS when they are identified in industry investigation reports. There is not a requirement for these data to be provided within investigation reports, but they are frequently assessed and therefore recorded as part of investigations. FRI data was reviewed by checking the 246 incidents to assess the frequency of calculation and entry of this information. An analysis of FI scores was attempted to investigate whether higher FI scores are correlated with fatigue-related incidents.

4 Results and discussion

4.1 Overview of fatigue's contribution to incidents

Of the 246 incidents available for analysis 21 % were found to have fatigue as a factor in one of the following categories and the data are presented in Table 3.

Table 3 - Incident level breakdown of fatigue-related incidents by incident factor type

Factor type	Definition	% of incident sample with fatigue as a factor
Causal or contributory factor	The event occurred, or the likelihood of the event occurring was increased because of fatigue.	6%
Performanc e shaping factor	A factor that is not identified as causal or contributory in the incident report and is not a human error or management failure, but fatigue is identified from the report as negatively influencing the event. For example, a driver identifies that they had some home-life related fatigue, but neither the individual nor the investigation identify this as causal or contributory to the incident.	15%
Percentage of fatigue-related incidents in full sample		21%

To put the fatigue data in a broader context, Figure 2 shows the 10 incident factor classifications used when analysing the incidents in the IFCS. As fatigue falls under 'Personal' this subcategory has been exploded to indicate the relevance of fatigue in this sample. It is important to bear in mind that

each incident can have unlimited and varying numbers of incident factors. Also there are human error classifications which form part of the IFCS, but have not been included in this analysis.

Figure 2 - Factor level overview of 10 incident factor contributions to sample data - Further breakdown of 'Personal' (1185 incident factors from sample of 246 incidents)

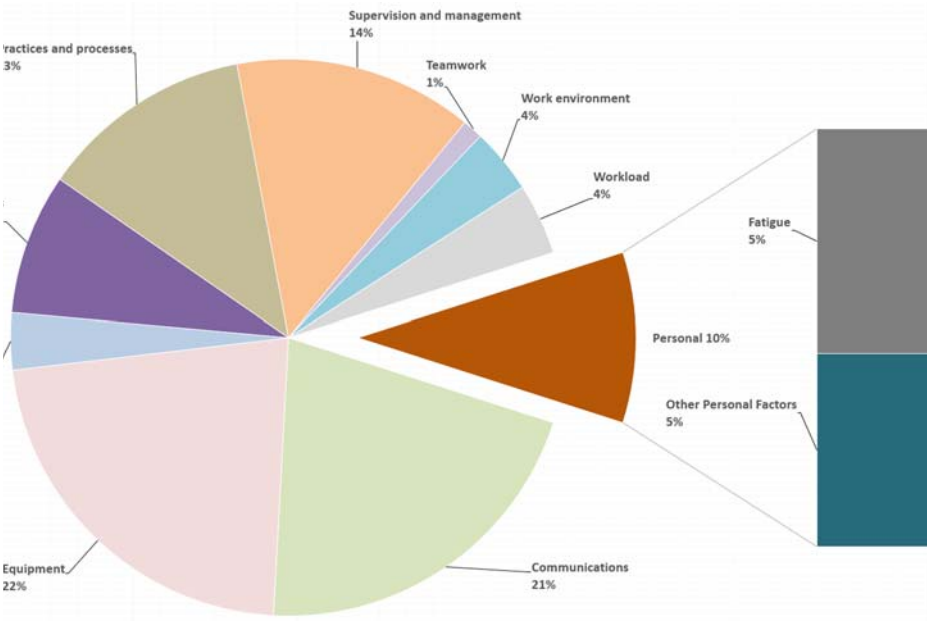


Table 4 summarises the type of incident in which fatigue was identified as a factor. Figure 3 identifies the role which fatigue was related to.

Table 4 - Breakdown of fatigue-related incidents by incident type

Fatigue Incident Type	Total
Collision	2
Collision with object	1
Collision with third party	1
Derailment	1
Near miss	2

Table 4 - Breakdown of fatigue-related incidents by incident type

Fatigue Incident Type	Total
Operating irregularity	8
SPAD	36
Grand total	**51**

Figure 3 - Breakdown of incidents by job role

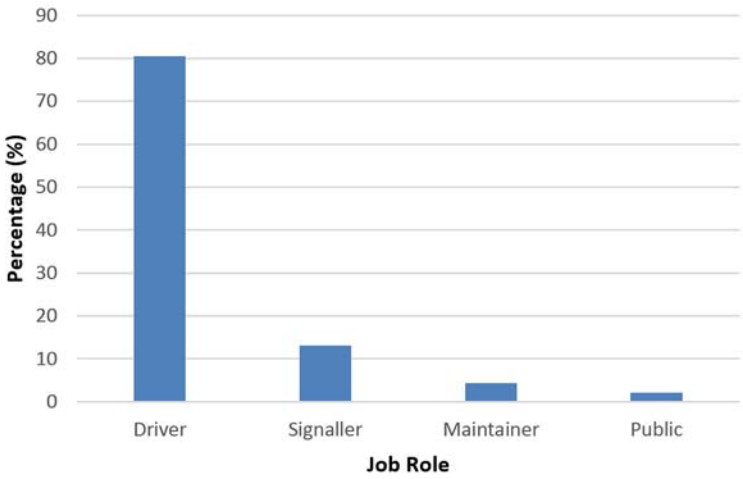


Figure 3 indicates that from the sample of 51 fatigue-related incidents the large majority (~80 %) of affected individuals are train drivers followed by signallers. There are a variety of reasons for this such as the nature of the tasks being conducted, as when driving (especially in freight operations) tasks can be particularly susceptible to fatigue. However this is primarily influenced by the fact that driver-related incidents, particularly SPAD reports have been made more readily available for the database as can be seen in Table 4 and potentially that fatigue may be more routinely considered for drivers in these SPAD events.

As the data in Table 3 shows, fatigue caused or contributed to incidents in only 6 % of our sampled cases. This is the first time that data on the relative importance of fatigue has been collected and highlights that fatigue can have a direct causal impact on key risk-related incidents.

There is however, a possibility that this is an under-estimate related to challenges in investigating fatigue and the challenges in drawing a clear link in causal analyses between fatigue issues and human performance in incidents. This may occur because staff do not wish to report fatigue, particularly if it is related to home-life issues or the prevailing organisational culture creates a perception that such reports may bring adverse consequences for the individual. The challenge in terms of causal analysis can be that unless an individual is actually asleep, fatigue only has an influence on the error type rather than a direct link to the incident, but in these circumstances it is usually classified as a PSF in the database. For example, a person may report feeling tired but this may not be due to a system failure (unmonitored overtime, inappropriate rostering) or be identified as contributory to the incident. This is supported by the larger proportion of fatigue PSFs (15 %) as shown in Table 3. When causal/contributory and performance shaping factors are taken as a whole, the overall contribution of fatigue to incidents is 21 %. That approximately one fifth of incidents have fatigue as a factor highlights the importance of fatigue to incidents.

There is a challenge to fully understand the contribution of these factors to incidents, however this is an important collection of data from which we can learn by starting to look across incidents to understand the types of fatigue issue which occur.

4.2 Learning from the types of fatigue issue experienced

To understand how fatigue-related incidents are analysed and classified some examples of incident factor classifications from IFCS are provided in Table 5.

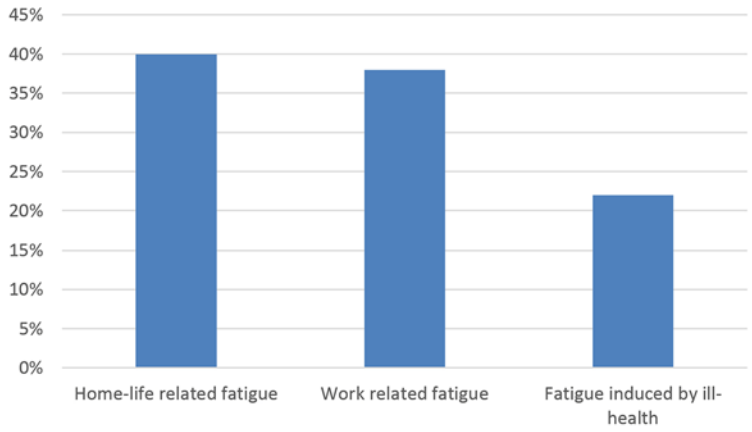
The incident factor descriptions from the IFCS (Table 5) are taken directly from the provided incident report. These are beneficial as they allow the reader to understand the level of fatigue (if enough detail provided) and its source. It is planned that industry will be able to search and review these factors within the Incident Factor Classification System in the future.

Table 5 - Examples of incident classifications from IFCS for different sources of fatigue

	Fatigue Source		
Ex.	**Home-life related**	**Work related**	**Induced by ill-health**
1.	'The driver drank a carbonated drink on an empty stomach and experienced abdominal pain. This disturbed his sleep which may have contributed to the incident.'… 'The driver states that during driving he did not feel any further discomfort but did feel slightly tired.'	'The working hours of the driver were in excess of industry guidelines, resulting in high Risk and Fatigue Index Levels. In the 4 weeks prior to the incident the driver had worked over 12 hours in a shift on 3 occasions and had less than 12 hours rest on 3 occasions.'	'The driver was on several forms of medication for his diabetes, back pains, depression, high cholesterol and diarrhoea. This concoction of medication is likely to have made the driver feel tired and drowsy.'
2.	'The previous night the driver had been woken by their noisy neighbours at approximately 0130. Also the night prior to duty, the clocks had gone forward for spring.'	'The driver had worked 11 out of the last 14 days; a week of nights, then only 24 hours' rest followed by early shifts. The fatigue index for the shift pattern was high.'	'Signaller had a disturbed sleep pattern prior to shift due to lingering flu virus. The flu virus had caused the Signaller to be sick for 5 days. Signaller further stated he/she still felt tired and lethargic. This could have contributed to a lack of concentration.'
3.	'It was noted that during the interview with the driver he indicated that he had problems with his private life at home. This had led to him being tired due to not having enough sleep the night before the incident.'	'The signaller stated that he was tired on the day of the incident due to excessive working hours.'	'The driver stated that he regularly has a disturbed night's sleep due to his medical condition, however he considers the level of disturbance is minimal, with little or no effect on his personal fatigue.'

Figure 4 shows a breakdown of the identified source of fatigue for all fatigue-related incidents. Home-life related fatigue was the most common source, present in 40 % of the total sample. This may be expected as it is the source with least control by the industry with influences such as social activities and domestic home life. Work-related fatigue contributed to 38 % of incidents. This indicates that there are some areas which can be focused on by the industry in managing fatigue in the workplace such as regular working of rest days, night-shift duties and design of tasks. Ill-health related fatigue was the smallest contributor to fatigue in 21 % of incidents including issues such as lack of sleep or poor quality sleep caused by medication, disorders (e.g. sleep apnoea, restless leg syndrome) and mild illnesses. Nevertheless, this is still a cause for a large proportion of fatigue-related incidents and deserves significant attention.

Figure 4 - Breakdown of fatigue source for all fatigue-related incidents (n=54)

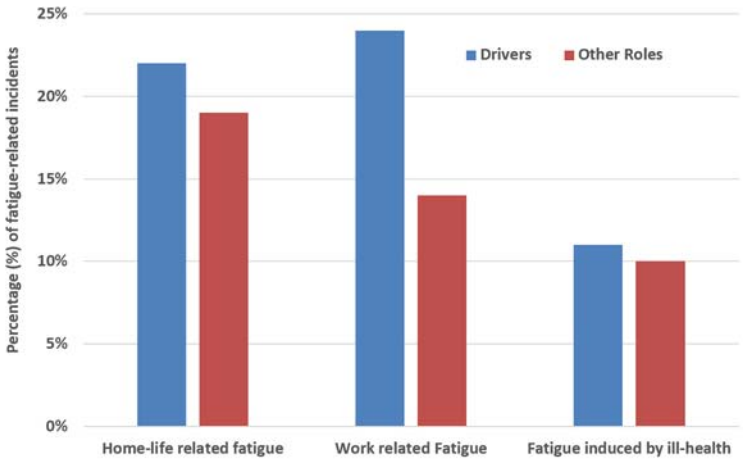


A simple comparison between drivers and non-drivers was made in an attempt to identify if there was any noticeable differences in the profiles for fatigue source. The driver sample was larger than the remaining job roles so results for non-drivers were extrapolated[2]. This identified that there were differences in fatigue source with drivers attributing 24 % of fatigue-related incidents to work-related factors whereas this value is only 14 % for all other roles (Figure

2 Fatigue source data was estimated beyond the original observation range for non-drivers (n=22) to the same ratio to allow comparison in percentage terms against drivers (n=29).

5). Home-life and ill health related fatigue did not vary greatly between drivers and non-drivers. The data may highlight that work related fatigue is better investigated for driver incidents.

Figure 5 - Breakdown of fatigue source for drivers (n=29) vs. non-drivers (n=22) in all fatigue-related incidents



4.3 Analysis of SMIS database reporting

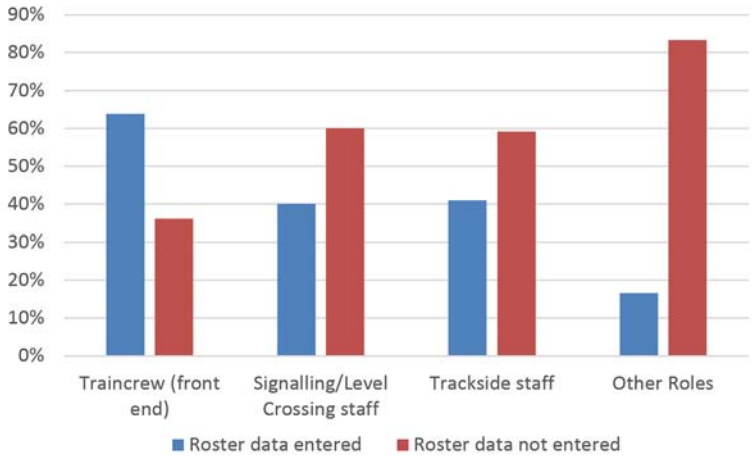
In the sample of 246 incidents analysed only 1 % had the relevant radio check box selected to indicate fatigue was a factor. However, our analysis revealed that 21 % of incidents were fatigue-related. This indicates the SMIS fields under 'Cause Summary' > 'Cause Detail'/'Underlying Causes' are not routinely being completed, possibly due to the fact they are non-mandatory. Currently there are no fields in SMIS to enter a fatigue index or risk index value whereas the IFCS database allows a FI value can be captured.

Analysis of the sample data extracted from the SMIS database used in this report has shown the frequency of data entry in the non-mandatory fields that can be useful for understanding the individuals fatigue.

In the sample data, fields present in SMIS to input the individual's roster pattern were only completed for 58 % of incidents. Further analysis revealed that where a driver was involved in the incident, their roster pattern was entered 64 % of the time compared to other roles such as signallers and maintenance staff with 40 % and 41 % entry rates respectively (Figure 6). Even in an incident where the driver was not at fault (such as a near miss with

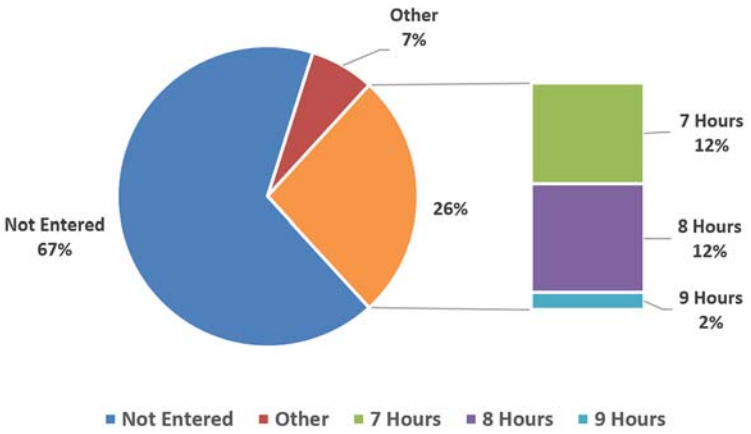
a track worker working without a lookout) the driver's roster pattern was recorded however the track worker's was not.

Figure 6 - Roster data entry vs job role



Fields available in SMIS to enter data regarding the individual's duration of sleep (the night prior to the incident) were completed for 33 % of the total incident sample (Figure 7). For the 51 fatigue-related incidents this was completed for 26 % of incidents. Duration of sleep is an important factor that has a large influence on fatigue - especially with night shifts and first shift worked. It is therefore important to accurately record this value where possible, as it may be an important indicator of fatigue being an underlying cause to an incident even if the individual involved says they did not feel fatigued at the time.

Figure 7 - SMIS data entry statistics for 'Duration of sleep' and breakdown of sample results



The accurate recording of this information may assist in the understanding the factors behind the incidents and potentially predict whether fatigue was a likely influencer to the incident. Whilst elements of fatigue-related data are captured in the IFCS, this is only for a relatively small sample of incidents, and wider data capture within SMIS would support our understanding in this area.

4.4 FRI data review and analysis

FI calculations were only available in 16 % of incident reports. This indicates that it is either not being used, being used but not reported or only reported for certain incidents.

An attempt was made to observe any correlations present between FI score and the occurrence of a fatigue-related incident however it was later understood (based on information from ORR) that the rostering system (Crewplan) used by the majority of train operating companies (TOC) and freight operating companies (FOC) has the FI calculation tool built-in resulting in many companies using different and outdated versions of the FI tool. As a result of this issue, the FI analysis is not presented in this report.

Analysis of the wording in the incident reports around the use of the FRI leads us to believe that some incident investigators are not using the FRI as intended (reporting FI and RI scores per shift individually) but are reporting a score equalling to the average over the whole shift pattern which has the potential of masking high peaks for individual shifts. Another challenge around the use of FRI scores is the interpretation and how organisations respond to the values obtained.

Six incident reports contained this or a similar phrase:

> *'...their shift pattern was subject to the fatigue calculator and fatigue was discounted as a factor.'*

This indicates the FI scores had been calculated but not included in the report; sometimes despite the fact the individual had explicitly stated they were suffering from fatigue. Also, this approach to solely using the FRI tool to confirm or dismiss whether an individual was fatigued should be avoided as factors such as length and quality of sleep are not accounted for, which have a large impact on fatigue. ORR (2012) guidance in their Managing Rail Staff Fatigue document explains how a fatigue assessment tool can be used to identify potential problems with a roster pattern however also identifies the limitations present with such tools and the need to *'think carefully about what the output actually means rather than to blindly assume it produces an authoritative satisfactory/unsatisfactory decision'*.

5 Conclusions

This writing of this special topic report has proved beneficial as this is the first time, due to the development of the IFCS, that we have been able to focus on reviewing fatigue issues related to a sample of high risk railway incidents. This has been carried out using the IFCS element of SMIS and is based on the review of industry investigation reports by human factors specialists at RSSB. SMIS alone indicated that fatigue played a role in 1 % of the 246 incidents. However, the IFCS analysis has identified that fatigue is an important contributor to incidents. Of the sampled incidents, 6 % have fatigue as causal or contributory factors; and fatigue played some part in 21 % of all incidents in the sample. This shows that the relevant check box in SMIS for fatigue is mostly not being used, and highlights the importance of RSSB's work through the classification of incidents in the IFCS.

It has not been possible in the past to analyse a collection of data on fatigue from one database. The analysis of data in this report from the IFCS has highlighted a number of factors that enable fatigue to have an impact on work activities in the rail industry. At a high level these include factors related to work, home and the individual (including health) as well as the areas that have had much attention such as shift-work, roster patterns and the need for quality sleep. There are also other factors that often go unnoticed. This is the first time that we have been able to better understand these factors by looking at fatigue issues across incidents to understand their direct role in safety. The data can be used to better inform our understanding and management of fatigue.

Determining the role of fatigue in incidents remains a challenge, however, by talking to drivers, understanding their roster patterns and other fatigue inducing factors, investigators can make judgements about the role of fatigue (if present) in incidents. For human factors this is often all that we can do and there is not a truly objective measure of how fatigued a person was at the time of an incident or the extent to which that affected the individual's performance at the time. Any classification of human error relies on trying to understand the intentions of the individual and we can only really identify that by talking to them. In the same way, assessing the likely contribution of fatigue relies on piecing together some elements of circumstance and reports

from the person involved. Investigations should still be able to judge the likelihood that the individual involved was suffering from fatigue provided the reports are accurate and the individual has been truthful when providing their statement of events, as a lot of information such as duration of sleep can only be gained from the individual. A key challenge therefore is to create a culture and environment where staff feel able to describe any fatigue-related factors during investigations and know they will be treated fairly without fear of retribution. Only this way will the industry be able to gain the relevant information to understand the causes of fatigue and continue to develop new strategies to eradicate it from the outset.

For organisations where safety-critical work is conducted the best method of managing fatigue is the use of a FRMS that is well designed to suit the organisation. This highlights the importance of recording and sharing data as it can be used to inform the FRMS and pro-actively attempt to eliminate the sources of fatigue and prevent any ill-effects from occurring. However, as some variables are unpredictable (especially home and health related) this will not always be possible. As well as the need for the organisation to manage staff fatigue, it is the individual's responsibility to ensure they gain sufficient good quality rest to reduce/eliminate fatigue where possible. In cases where this cannot be achieved it is important staff are trained well to know if they are fit for work and have an adequate method of reporting if they are not, without fear of any negative implications.

6 Recommendations

The industry currently acknowledges the risks associated with working while tired and understands that the management of fatigue for all employees (including those who drive trains, maintain the railways, manage the workforce etc.) is essential to mitigate these risks. As well as providing knowledge of the industry's current position with regard to fatigue, this special topic report has been able to make some recommendations that may improve the industry's understanding and management of fatigue.

1 This report has only looked at a small sample of 246 incidents that were available. It will be beneficial to do similar analyses of a wider sample, or for all incidents on a regular basis using the Incident Factor Classification System approach - Action for RSSB Human Factors (HF) team.

2 An overall review of the IFCS database incident factor sub-categories may be beneficial to better categorise incidents; especially fatigue-related incidents as currently issues such as ill-health are separate to fatigue - Action for RSSB HF team.

3 In the short term, to encourage the completion of non-mandatory fields in SMIS related to fatigue, so when necessary, analysis can be made with as complete a data-set as possible. This includes fields related to factors such as roster pattern, sleep duration, commute time.

    a Long-term action to make these fields mandatory by agreement with the industry - Action: RSSB's System Safety Team to develop proposals for consultation as part of the next update of RGS GE/RT8047.

4 Industry to improve the quality of fatigue assessment and reporting in incident investigations. This can be improved by the provision of better guidance on how to investigate fatigue within wider proposals related to human factors and investigations. - This action has been agreed with DRSG.

A Literature review

A brief review of the literature on fatigue (primarily in the railway industry) was conducted. 10 relevant papers were selected for appraisal including the proceedings of research completed by RSSB.

When trying to quantify fatigue it is important to understand the individual's own perception of their level of fatigue. There are a number of subjective fatigue assessment techniques such as the Karolinska Sleepiness Scale (KSS) which ranges from 1-Very Alert to 9-Very Sleepy, fighting sleep or an effort to keep awake. Although it may be easy to 'cheat' or not give true answers, the KSS has been validated by comparing results given with physiological indicators of sleepiness and has proven very reliable (Kaida et al., 2006). Stone et al. (2007) used subjective assessments of mental tiredness to indicate that early morning and night shifts are where operators feel they are most at risk from fatigue. Using a similar technique they found a positive correlation between the length of shift and feeling of mental tiredness.

Excessive fatigue will continuously reduce performance until the individual is able to achieve restorative sleep and recover any sleep debts that have accumulated. If in this state there are physiological indicators of sleepiness that the individual would experience such as involuntary eye closure, wondering thoughts, yawning etc. However Kaplan et al. (2007) found that people have a limited ability to predict the onset of sleep as participants fell asleep at times when they thought sleep was highly unlikely and failed to fall asleep at times when they thought sleep was highly likely. This study however, only shows the ability of people to predict sleep onset and not whether they would take appropriate action in relation to the task to prevent a sleep-related accident.

Health including short-term mild infections to long-term disorders will have an effect on an individual's level of fatigue. Mild infections such as the common cold and flu are known to influence and usually increase a person's desire and needs for sleep to aid with immune response however, there are other long-term or chronic disorders which may regularly disrupt the normal sleep pattern and build a sleep debt. Obstructive Sleep Apnoea Syndrome (OSAS) has been studied and is known to have a significant negative effect on performance especially in transportation industries as sleep quality is severely degraded. Studies in the rail industry by Hack et al. (2007) and Renata et al. (2012) have both indicated that the prevalence of OSAS in their samples of rail workers was higher than the average for the relative populations. In the UK it was found that OSAS affected 7.3 % of respondents (higher than the population average of ~3 %) and therefore placed it as one of the top 5 health problems in the rail

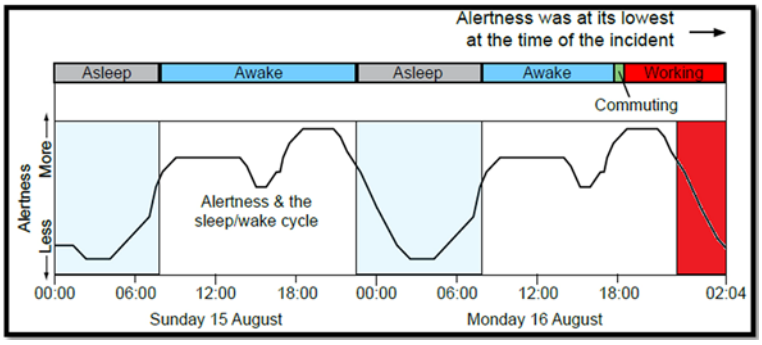
industry. Research at Brazilian railroads found 35 % of workers suffered from OSAS and these workers had higher BMI scores, were older and had been employed for longer. While 35 % seems high and was greater than the OSAS prevalence for the Brazilian population this was closer to the local population of the city of São Paulo. For many individuals the condition may go unnoticed so it is therefore important that we are more attentive to individuals with health conditions as they are more likely to be fatigued and have a higher risk of accidents at work.

High-workload is a known factor contributing to mental fatigue. Popkin (1999) found that high workload had a significant influence on fatigue defining workload as '(1) the demands of your work in terms of difficulty, complexity and time pressure; and (2) the effort you have to expend in meeting those demands'. This was investigated by Simoes et al. (2007) in relation to drivers and signallers in the railway sector. A subjective assessment using questionnaires and interviews was conducted and led to the findings that drivers often experienced high levels of stress and fatigue; particularly when operating the network under a malfunctioning condition as this increased the need for constant attention and awareness and therefore workload. The effects of this were perceived to be a reduced ability to make reasoned judgements and therefore a delay in decision making. A similar effect was found with the signallers who often had to multi-task under extreme time pressure and environmental noise. These operators highlighted that their performance was impaired due to their high workload, inadequate recovery time and irregular schedules and breaks.

A vast amount of research has been conducted into shift work in the railway industry as work and rest schedules are known to have a large influence on fatigue. This is largely due to the fact that shift work on the railways usually involves night work on a regular or rotating basis; requiring workers to sleep at a time that they would normally be engaging in activity, and to work when they may be least able to carry out tasks (Scott, 1994). This will disrupt the natural body clock and diurnal nature of humans which can impair both the quality and duration of sleep and increase fatigue levels in the worker. Figure 8 shows a normal circadian rhythm with an overlay of the train driver's sleep/wake/work pattern who was involved in the Shap incident. This indicates the incident occurred at a time of day where the body would usually be asleep, alertness at its lowest and therefore the individual was likely battling the natural urges to sleep. One influence of the circadian rhythm is the intensity and wavelength of ambient light. During the day the body secretes the hormone melatonin which has been shown to increase core temperature and

in turn increase alertness and performance. Conversely in the dark, the body decreases the production of melatonin reducing core temperature and inducing sleepiness (Skene, 2003). At the time of the Shap incident (approx. 2.00am) the environment was not only dark but comfortable and non-stimulating, further compounding the effects of sleepiness and reducing the driver's ability to fight it.

Figure 1 - Alertness vs. the sleep wake cycle (adapted from the RAIB Shap report)



The design of the task can also impact on the individuals fatigue and ability to combat it. Due to the monotonous nature of the freight train driving task and time of day these trains usually operate, there is a high incidence of fatigue reported in freight train driving operations. Research by Dorrian et al. (2007) found an association between fatigue and reduced freight driver performance and essentially safety. Fatigued drivers were observed to operate the throttle control less often, incur more speed violations and brake heavier than their rested counterparts as their driving became less well-planned. Not only does this have a negative impact on company profits and efficiency but also safety.

Along with their research into mental tiredness, Stone et al. (2007) analysed SPAD data held at the time of writing and found that the length of continuous driving period had a significant effect on risk of a SPAD occurring. After approximately four hours of continuous driving the risk of a SPAD occurring increases significantly (Figure 9) therefore highlighting the need for rest breaks at appropriately planned times.

Similarly, the SPAD risk increased with number of consecutive days worked; gradually over the first 6 days then increasing significantly on the seventh day (Figure 10). However, people are affected differently by fatigue, as Harma et

al. (2002) found that older drivers were able to tolerate higher levels of fatigue before feeling sleepy.

Figure 2 - Relative SPAD risk related to time on task (Stone et al, 2007).

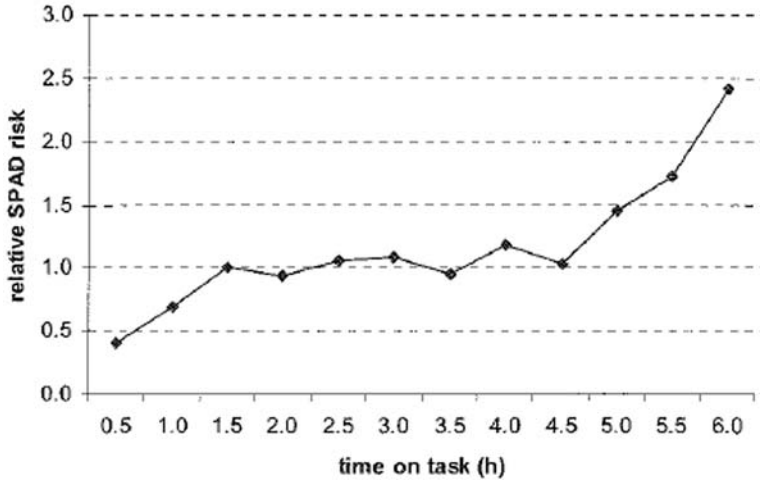
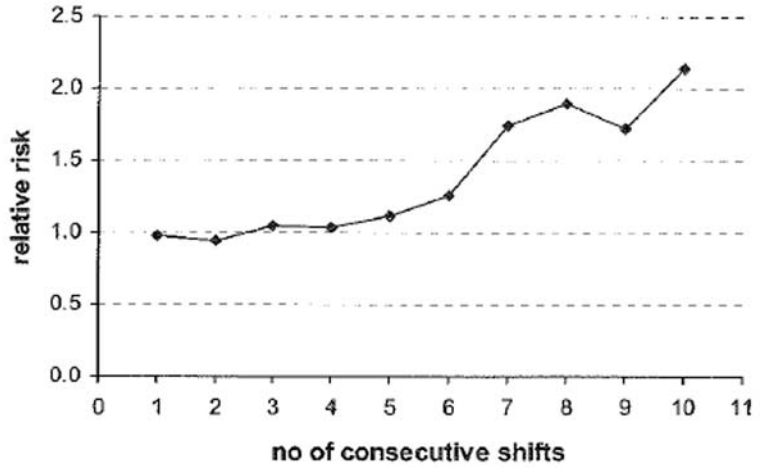


Figure 3 - SPAD risk over consecutive days (Stone et al, 2007).



The majority of this research in Appendix A combined with numerous other data sources has been used to create tools to evaluate and estimate the risk associated with irregular work-rest schedules and shift patterns such as the HSE Fatigue and Risk Index Assessment Tool commonly used in the UK rail industry.

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C Use of other biomathematical models

While the FRI model is the most widely used in the industry there are a number of other biomathematical models available to predict the likelihood of a shift pattern causing fatigue. These include:

- Boeing Alertness Model (BAM)
- Circadian Alertness Simulator (CAS)
- Fatigue Assessment Tool by InterDynamics (FAID)
- System for Aircrew Fatigue Evaluation (SAFE)
- Sleep, Activity, Fatigue, and Task Effectiveness model and Fatigue Avoidance Scheduling Tool (SAFTE-FAST)
- Sleep / Wake Predictor (SWP)

In the Shap investigation (RAIB, 2011) the investigators input the driver's shift pattern into four (unnamed) models (as well as the FRI) for comparison. The results were varied with two models predicting similar outcomes and the remaining two predicting very different outcomes. Only one predicted a high probability the driver was fatigued at the time of the incident.

From this it is evident that although bio-mathematical fatigue models and tools based on them can provide a useful indication of the level of fatigue which staff are likely to encounter, it is important that staff using them and interpreting their output are aware of the particular tool's assumptions and limitations. The models used in fatigue assessment tools do not "know" the level of fatigue staff will encounter when working a particular pattern, they merely make a mathematical prediction based on working hours and predicted opportunity for sleep. Recent reviews of fatigue models and tools and their uses (ITSR, 2010; CASA 2010; CASA 2014; Dawson et al, 2011) emphasise their limitations, and that they are only appropriate as one element in a wider fatigue risk management system.

Listed below are some of the benefits and limitations of using biomathematical models to predict fatigue:

Benefits	Limitations
They can assist in the identification of likely fatigue risks associated with current work schedules.	They are based on a set of mathematical predictions to estimate the probability of fatigue and relative risk of an incident.
They can assess the likely impact of fatigue associated with proposed changes to the working pattern.	They do not take account of the multiple causal factors of fatigue, e.g. individual differences, circadian type, commuting, job role, workload, work and non-work environment.
They can identify particular shifts or shift sequences within a work pattern associated with a higher risk of fatigue to enable risk reduction strategies to be implemented accordingly.	They make assumptions that individuals will get sleep of sufficient quality and quantity between shifts.
They can identify particular features associated with different shifts, shift sequences or work patterns and to estimate the benefits of compensatory measures such as providing additional breaks or shortening shifts.	The outputs should be treated with caution and used alongside other sources of fatigue information, such as staff reports and feedback, as part of the broader FRMS.
They can be used to explore whether fatigue was a contributory factor as part of incident investigations.	Recommended thresholds are not a definitive measure of a good fatigue control. They are indicative values based on the theoretical knowledge and assumptions made by the model's developers.
Some tools can be incorporated into an organisation's resource planning and monitoring systems.	They are not a substitution for a well thought out and comprehensive FRMS, but just one element of a company's overarching approach to effective fatigue management.

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