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Workplace Fatigue: The Impact of the Drive

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Abstract

Fatigue for many people has become an everyday occurrence, particularly due to the demands associated with work hours, lifestyle, work family balance, travel and commuting. Within a workplace hazards such as fatigue require particular consideration and risk mitigation strategies to ensure a safe workplace. One area requiring increased attention within the work environment is fatigue within the work driving context. Many people as part of their workday drive for work, and this activity has been identified as a high-risk work activity due to the significant injuries and fatalities attributed to work crashes. The demands associated with work and business and the geographical size of Australia can result in increasing amounts of time spent behind the wheel. Fatigue is a contributing factor to workplace crashes. Fatigue is a product of both physiological and environmental properties and has a significant impact on an individual's driving ability resulting from decreased psychological functioning, delayed reaction time, poor decision making, reduced attentiveness. Transport industry safety management systems operate implementing a variety of strategies aimed at reducing the risk of fatigue related incidents. However, the risk management, monitoring, and prevention of fatigue in the work driving setting offers unique challenges. This chapter provides an overview of previous fatigue risk management and research and some of the unique challenges associated with the measurement of fatigue. An adapted version of Dawson and McCulloch (2005) Safety Error Trajectory Framework is provided along with the implications to organisational culture and work driving safety across multiple organisational levels. This chapter concludes by suggesting a number of future directions for research and industry aiming to reduce the impact and frequency of fatigue crashes within the work environment.

Keywords: Fatigue, sleepiness, safety, safety management systems, driver incidents, measurement

1.0 Introduction

In an ever changing and competitive world of business, work, and careers, people are under pressure to do the job faster, more efficiently, get ahead in a job or career, optimise market share, and consequently are likely to work longer hours for career progression. In addition to the long hours associated with work, is the need to undertake activities to live a healthy and balanced lifestyle along with the challenges of family demands, travel for work, and daily commuting. For many people it appears that there never seems to be enough hours in the day and fatigue can be all too commonplace. People in today's society when asked "How are things going?" often reply with responses attesting to being extremely busy, closely followed up with comments about finishing each day extremely tired or worn out. Fatigue, particularly as a result of increasing life demands, has unfortunately become a daily occurrence. Travel and in particular driving for work also is a daily activity for many people either spending long periods of time in the commute to and from work or driving significant distances as part of their job. This chapter discusses fatigue, particularly within the work environment and outlines the different types of fatigue along with factors associated with fatigue. This chapter discusses the implications of fatigue within the work environment and in particular within the capacity of work-related driving and the implications associated with driving safely. It will conclude by highlighting the current strategies and interventions to address the issue of fatigue within the work driving context, the applicability of these strategies for managing fatigue in other areas of the workplace and their limitations suggestions for future research directions.

2.0 What is Fatigue?

The literature around fatigue, workplace fatigue, and driver fatigue, often employs different definitions for fatigue and often conflates fatigue with sleepiness. This is further complicated when the antecedents and consequences of fatigue and sleepiness are discussed. Traditionally, sleepiness is simply the tendency for an individual to fall asleep (Lerman et al., 2012). In this manner, sleepiness can be defined as a physiological state, akin to hunger or thirst, where an individual desires sleep (Mullins et al., 2014). Comparatively, fatigued can be defined as a body's response to reduced sleep or continued physical exertion (Lerman et al., 2012). However, fatigue does not exclusively come in physical forms with physical exhaustion or muscular fatigue (Lerman et al., 2012; Mullins et al., 2014; Shen et al., 2006), it can also come in the form of psychological and emotional exhaustion (Mullins et al., 2014). The exhaustion associated with fatigue has also been described as a lack of energy or tiredness that leads to decreased physical or psychological functioning (Shen et al., 2006). This inclusion of tiredness in this definition of fatigue places sleepiness within the bounds of fatigue.

Fatigue and sleepiness have a variety of contributory factors. For instance, biological processes such as circadian rhythms and their variability regulate the human sleep cycles (Lerman et al., 2012), and the homeostatic process balances time awake and time asleep (Satterfield & Van Dongen, 2013). Researchers have also described that some of the antecedents of fatigue include time on task and an individual's cognitive load (Mullins et al., 2014). Research has demonstrated that prolonged cognitive load in the form of a series of strenuous mental tasks significantly increased subjective rating of fatigue and decreased parasympathetic nervous system activity, indicating the body leaves the resting state when experiencing fatigue (Mizuno et al., 2011). Research also indicates that time on task impacts sleepiness with increased length of time spent in a simulated driving activity leading to subjective sleepiness gradually increasing (Ting et al., 2008). Finally, there are a variety of sleep disorders such as sleep apnoea, insomnia, and narcolepsy, which have the capacity to contribute to fatigue and tiredness (Lerman et al., 2012). This is not a comprehensive list of the antecedents for

fatigue and sleepiness, and indeed, many of these antecedents encompass both fatigue and sleepiness.

There are also a variety of consequences from individuals experiencing fatigue and sleepiness that will be discussed at length in this chapter. For example: individuals experiencing fatigue display hampered muscle activity and reduced cognitive function due to fatigue that is the result of extended periods of activity (Abd-Elfattah et al., 2015; Lerman et al., 2012). Similarly, individuals experiencing sleepiness display a decreased ability to pay attention to detail, slower reaction time, and impaired judgement when making decisions (Lerman et al., 2012). Such consequences and how they apply to the driving context will be discussed at length in this chapter. With the variety of definitions of fatigue and sleepiness it would take a full literature review to clarify their meaning, their independent antecedents, and their unique consequences. That is not the purpose of this chapter. As such, this chapter will define sleepiness as the tendency fall asleep, and fatigue as the broader experience of psychological and physical exhaustion, in this way, fatigue would be inclusive of sleepiness.

3.0 Causes of Fatigue

3.1 The Neurobiology of Fatigue

At a biological level, sleepiness is the result of two primary processes: The circadian rhythm and the homeostatic process (Satterfield & Van Dongen, 2013). The circadian rhythm is the biological clock governed by the hypothalamus and causes a daily cycle of sleepiness. While this cycle is not completely dependent on light, it is heavily impacted by the light that enters the eyes (Sack et al., 2007). Broadly, the circadian rhythm is the process that causes a person's feelings of sleepiness at night and alertness during the day (Satterfield & Van Dongen, 2013) along with feelings of a slight increase in sleepiness in mid-afternoon (Sack et al., 2007). Research demonstrates that an increase in workplace fatigue related incidents coincides with circadian rhythm peak times of sleepiness (Lerman et al., 2012). For example, a study using a sample of engineer shift workers, found that workplace injuries were more likely to occur during the night shift compared to the day shift (Smith et al., 1994). Furthermore, a study on French Firefighters demonstrated that they experienced the greatest amount of work-related injuries around 2400 hours to 0400 hours (Riedel et al., 2011) which once again coincides with low points in circadian rhythms.

The homeostatic process acts in a different manner to the circadian rhythm (Satterfield & Van Dongen, 2013). Rather than causing sleepiness due to the amount of light entering the eyes, it seeks to balance the amount of sleep and wakefulness directly. It increases pressure for an individual to sleep (by making a person feel sleepy) with the increase in time being awake, and removes this pressure with the increase in time spent asleep (Satterfield & Van Dongen, 2013; Van Dongen & Dinges, 2000). That is, the longer an individual is awake, the more they feel like they need to sleep no matter what time of the day it is. The homeostatic process and the circadian rhythm are both complex processes that interact with one another in a non-linear manner and it is not currently possible to estimate the relative impact the two processes have on sleepiness (Van Dongen & Dinges, 2000). However, these two neurobiological processes have direct relevance for organisational policy and in particular workplace driving. Employee shift and work timetabling should not only consider the particular times of the day associated with circadian rhythms, but also should consider previous sleep patterns and quality of sleep experienced by employees in days and times prior to and during work tasks and shifts.

3.2 Time on Task and Cognitive Load

In addition to the time of day and humans innate biological response, there are several environmental factors that can contribute to sleepiness and fatigue. One such contributing factor is the cognitive load of prolonged time spent on a singular task. An example a study using a driving simulator found that time on task (and time of day) impacted self-reported levels of sleepiness as participants performed six one-hour sessions in a simulator (Åkerstedt et al., 2010). In addition to subjective sleepiness, the results also demonstrated other physical measures linked to unsafe driving such as lane variability and blink duration which were negatively impacted with increased time on task in the simulator (Åkerstedt et al., 2010). Time on task not only impacts physiological and subjective sleepiness, it also impacts individual's cognitive performance. For instance, research on standardised testing in school and university settings has shown that with each hour later in the day that a test occurs, average performance on tests decreases slightly (Ackerman & Kanfer, 2009; Sievertsen et al., 2016). However, with small breaks of 20-30 minutes, test scores can increase (Sievertsen et al., 2016). Furthermore, research performed with computer-based attention maintenance tasks found that sustained cognitive effort resulted in deficits in individual's executive attentional abilities (Mizuno et al., 2011). These results therefore demonstrate that within a work setting, sustained attention can have a profound impact on an individual's level of cognitive fatigue and their ability to function at a high level. Consequently, not only does time on task and cognitive load impact upon work performance, but they also have serious safety implications associated with work driving tasks.

3.3 Environmental Issues

There are a range of factors associated with the physical environment that can also impact an individual's level of fatigue. For example, internal lighting provides a clear example of an environmental factor that could influence fatigue due to the influence that natural light has with circadian rhythms. Previous research has shown that the inclusion of bright lights (1000 lux compared to 100 lux) during artificial night shifts prevented the reduction in alertness and improved individuals' performance on cognitive tests (Campbell & Dawson, 1990). Part of the process of nocturnal work and the exposure to artificial light during that shift (i.e. nurses working a night shift) is the returning to a normal sleep cycle. This transition from night shift to a normal day/night sleep cycle forces changes to the circadian cycle. Continued disruptions to these normal cycles can be associated with health issues (Scheer et al., 2009) including diabetes (Knutson et al., 2006) and hypertension (Gangwisch et al., 2006). More recent research indicates that filtering out part of the light spectrum (light below 480nm) during night shifts can prevent the severe impact on the circadian rhythm and result in improved alertness the next morning (Rahman et al., 2011). While this may provide some benefit to workers associated with shift work it remains unclear as to the direct benefit that this may offer drivers. In addition, workers ability and safety associated with driving home after such night shifts may still be compromised. Research also suggests that temperature is also a factor that can influence individual experiences of fatigue. Higher temperatures tend to produce reduced rates of performance on cognitive tasks and vigilance tasks (Lerman et al., 2012). Temperatures at the lower end of the comfort spectrum (20C/68F) are recommended for indoor workplaces to avoid drowsiness (Lerman et al., 2012). While it is evident that light and temperature can affect fatigue, which has implications for workplace design to reduce the impact of fatigue, other factors associated with fatigue are also important.

3.4 Time Without Sleep

A major factor associated with workplace fatigue is simply the lack of sleep or the lack of quality sleep. Time without sleep can be separated into chronic lack of sleep and acute lack of sleep (Shen et al., 2006; Winwood et al., 2005). Acute lack of sleep is the occurrence of a bad night's sleep during

the previous 24-hour period, whereas chronic lack of sleep occurs when a person experiences some form of persistence or ongoing instances of a reduced amount of sleep. Generally, adults require 7-9 hours of sleep in each 24-hour period to remain healthy (Hirshkowitz et al., 2015). However, sleep quality has also been identified as being extremely important in its relation to fatigue (Nicassio et al., 2002), with continuous uninterrupted sleep being the most beneficial in staving off sleepiness. There are a variety of potential causes for a persistence of reduced sleep including chronic diseases, medication, or environmental factors (Colten & Altevogt, 2006) many of which are common within work driving settings.

4.0 Measuring Fatigue at Work

There are a variety of challenges associated with definitively measuring fatigue and consequently many organisations adopt a risk management approach to addressing the risks and safety implications associated with fatigue. For example, within the transport sector in Australia there exist established limitations regarding the number of hours a vehicle can be driven for work in a 24-hour period. Consequently, risk management and mitigation strategies are commonly implemented throughout typical high-risk work sectors such as mining, gas, and utility sectors. In contrast, other work sectors may have more flexible arrangements due to perceptions of less risk or challenges with resourcing demands. For example, health professionals or first responders often must work despite fatigue. For instance, due to particular unscheduled job demand or an extreme incident occurring toward the end of a shift such workers may be required to respond, and as a result, work a shift longer than 12 hours. When such shifts occur in a health care context it can lead to a variety of negative outcomes for the workers on-the-job performance (Rogers et al., 2004), with shift work in general leading to an experience of burnout (Wisetborisut et al., 2014).

The risk management process not only includes mandating shift length or time between shifts to ensure employees have the opportunity for sleep, but also monitoring fatigue to determine if workers have adequately rested. There are a variety of methods available for measuring or monitoring fatigue, with the manner in which fatigue is monitored often being a product of the context of the work. While within a work setting, accurately measuring fatigue is highly important to maintain maintaining safety for the entire workplace. There are several challenges associated with fatigue measurement with the cost and availability of technology along with the task being performed and what is actually being measured. In addition to ensuring safety within a workplace, not only do fatigue risk monitoring and management strategies need to be scientifically accurate, but they also need to be accepted as valid, if required to be used as evidence in cases where fatigue may have contributed to an incident (Dawson et al., 2014). Fatigue measurement and monitoring methods can broadly be defined as fitness for duty tests, continuous operator monitoring, or performance-based monitoring.

4.1 Fitness for Duty Tests

Fitness for duty tests are undertaken as assessments that occur prior to an employee having the opportunity, or being permitted, to perform the task that is part of their work. Often these assessments employ technology as a test of reaction time or general cognitive performance on a brief task which are used as proxy measures for fatigue (Dawson et al., 2014). These methods suggest that if an employee performs above a pre-set standard, then they are deemed to not be fatigued and therefore fit for work. However, a limitation associated with this type of fatigue measurement is there is little evidence that these fitness for duty tests are predictive of fatigue that is experienced across the course of a work shift. Therefore, in regard to fatigue, it is actually only a measure of an employee's level of fatigue at the beginning of their shift in contrast to a measure

predicting fatigue that may be experienced at some stage after that time (Dawson et al., 2014). Furthermore, in regard to fatigue that may occur during the course of a shift, research suggests that there is little consensus as to the frequency with which these tests should be administered across a shift (Dawson et al., 2014).

The psychomotor vigilance task (PVT) is heralded as the golden standard for measuring fatigue in this manner (Dawson et al., 2014). The PVT is a reaction time test and involves a participant waiting for an expected stimulus (a small bright light on a computer screen) and immediately pressing a button in response to it appearing (Dinges & Powell, 1985). The assessment usually lasts 10 minutes with intervals between the appearance of the stimulus varying between 2-10 seconds (Dinges & Powell, 1985). This measures an individual's reaction time to the stimulus, and their ability to maintain attention to the simple task (Matthews et al., 2017). In the context of measuring driver fatigue, reductions in driver performance is associated with reductions in performance on the PVT. A simulated driving exercise and PVT assessment repeatedly occurring across a 24-hour period with increasing time awake at each assessment found that both driving performance and PVT performance both degraded with the lack of sleep (Baulk et al., 2008). However, the authors of this research highlight that reduction in performance in driving performance as a result of time awake was highly variable between participants, but the reduction performance in the PVT as a result of time awake was comparably very stable and did not vary. They describe how this indicates that PVT reaction time is not a sufficient measure of fatigue, and should be used in assessments accompanied by other tests (Baulk et al., 2008).

4.2 Continuous Operator Monitoring

These assessments measure an individual's fatigue during work. This is done by measuring proxy physiological indicators of fatigue. Unlike Fitness for Duty Tests, these methods can be very costly (Dawson et al., 2014). This is due not only to the purchase price of the technology used, but also due to the fact that every employee on shift would require this technology to accompany them while they are on shift. Common forms of this technology include measures of eye movements or blink frequency, where others measure brainwaves through EEG, or galvanic skin resistance (Dawson et al., 2014). Such techniques of continuously measuring fatigue can not only be costly, they could potentially hinder individual work performance with their physical presence in the workplace. Within the heavy vehicle transport sector, recent developments in the technology space have resulted in technology being trialled that continuously monitors drivers via in cabin cameras and infrared technology. The purpose of this being to monitor in real time driver's using facial, eye, and head movements, in addition to other aspects associated with vehicle movements, as indicators of fatigue (Wishart, 2020). The technology utilises a series of algorithms to, in real time, process information and determine if an event should be defined as an indicator of fatigue. From there a notification can be sent to a designated fleet or transport operator and a series of alarms and alerts within the vehicle cabin can be triggered, alerting the driver and preventing the fatigue from resulting in a road incident. While this technology appears to offer some safety related benefits through real time event notification and preventing a fatigue crash, it does not prevent the instance of fatigue events occurring nor predict the possibility of fatigue prior to the driving task.

4.3 Performance Based Monitoring

Performance based monitoring while not directly measuring fatigue offers some opportunity as a pseudo measure of fatigue by measuring the continuous performance of an individual. It is believed that measuring an individual's performance can provide information as to if the individual is experiencing fatigue (Dawson et al., 2014). For instance, if an individual's work performance is

decreasing or in the case of a driver, they are making fewer within lane corrections, or the vehicle is failing to stay within the designated lane, then this could indicate that the person is fatigued (Dawson et al., 2014). It is important to note that performance based monitoring requires fatigue to have already impacted an individual's performance, and consequently such an approach could have substantial safety implications whereby a fatigued person's reduced performance, if not noticed immediately, could result in a serious workplace incident. Therefore, in performance based monitoring, if used as a fatigue prevention strategy, it is important to find the correct balance whereby quality of performance has been impacted to an extent that it would indicate fatigue, but where it would not yet be impacting upon safety.

5.0 Fatigue in the Work Driving Context

Driving for work has been established as one of the riskiest activities that a person can do in the performance of their job, due to the over representation of work related crashes and injuries that occur while driving for work purposes (Haworth et al., 2000; Mitchell et al., 2012; WHO, 2004; Wishart, 2015; Wishart et al., 2011). According to Safe Work Australia (2017) in Australia during the 14 years from 2003 to 2016 approximately 2/3rds of all workplace fatalities involved vehicles indicating that vehicles are the highest mechanism of injury to Australian worker fatalities. Experiencing fatigue vastly increases the likelihood of a workplace incident occurring and 30% of serious workplace injuries are fatigue related (Australian Transport Council, 2011). Given the prevalence of fatigue related workplace injuries and the over representation of work driving crashes in worker fatalities, work driving fatigue is believed to be one of the most important factors contributing to all road crashes (Haworth et al., 2000). Furthermore, due to the vastness of countries like Australia, many people drive long distances either for holidays, pleasure, or commuting and travelling for work. Consequently, fatigue is a particularly pertinent issue in the driving community as a result of long-distance travel, monotony, and exposure factors. Other factors that contribute to fatigue within the work driving environment include, work pressure, shift work, personal circumstances, health and well-being, inadequate amount or quality of sleep, sustained mental or physical effort, disruption of circadian rhythms (the daily cycle of waking and sleeping), inadequate rest breaks, and environmental stresses (heat and noise; Lerman et al., 2012).

To provide further context of the issue of fatigue while driving approximately 20-30% of fatalities and serious injuries resulting in road incidents can be attributed to sleepiness (Australian Transport Council, 2011). With the frequency of fatigue related crashes, organisational and road safety stakeholders highlight the importance of addressing the problem of fatigue in the workplace driving context. However, one of the major challenges associated with fatigue related crashes, and subsequently their prevention, is the difficulty in determining if fatigue played a role in a road incident. Consequently, it is likely that fatigue related crash statistics, while alarming, are potentially grossly underreported. For example, estimations of fatigue related crashes vary across Australian states, due to different methods of measurement and assessment that currently exist (Dawson et al., 2018). Whether or not fatigue is recorded as a contributory factor can often depend upon the outcomes from an investigation utilising subjective assessments or after the fact determinations whereby other potential factors are ruled out, leaving fatigue as the only other potential contributing factor (Dawson et al., 2018). Therefore, the frequency of fatigue as a contributing factor in crashes can vary substantially depending upon the method used (Dawson et al., 2018).

Research conducted in the United States also provides compelling evidence as to detrimental effects of fatigue on driving safety. The National Highway Traffic Safety Administration's National Motor Vehicle Crash Causation Survey consisting of a representative sample of police-reported road incidents reported that when an individual had 4 hours, or less, of sleep, the next day they were 11.5 times more likely to be involved in a road incident, compared to an individual who had at least 7 hours of sleep (AAA Foundation for Traffic Safety, 2016). The results also indicated that the

likelihood of crash involvement due to fatigue decreases with each extra hour of sleep that drivers were able to get the previous night (AAA Foundation for Traffic Safety, 2016). Further evidence attesting to the impact of fatigue upon the safe driving context can also be demonstrated by the danger associated with travelling in a vehicle with eyes even closing for a short time. For example, a driver travelling in a vehicle at 100km/h will cover a distance of 111 metres, more than the length of a standard football field, if they happen to not look at the road or close their eyes for a period of 4 seconds.

Other Australian research has highlighted the effects of fatigue by demonstrating that a person who has been awake for 17-19 hours has performance capabilities similar to being impaired by alcohol to a blood alcohol content equivalent 0.05%, the legal limit in Australia for most drivers (Dawson & Reid, 1997; Williamson & Feyer, 2000). This research provides an indication of the alarming evidence associated with the impact of fatigue. For instance, unlike alcohol impairment whereby there is an easily administered breath test reading that can determine the level of blood alcohol in a person's system, there currently is no such measurement indicator for fatigue.

Within the driving environment, lane variability and lane drifting can also be a fatigue related factor that can result in head on collisions or run off road type crashes. Lane drift incidents have the propensity to increase gradually with the increased number of hours that the driver has spent awake. A simulated driving study found that after approximately 3, 8, 18, and 24 hours awake, incidents of lane drifting increased at each increment, with a large spike in lane drift incidents occurring after 24+ hours (Baulk et al., 2006). Fatigue and lane drift can also be influenced by the monotony of the task that is being performed. Research has demonstrated that when performing a monotonous driving activity that lasted one hour, driver's number of out of lane variations significantly increased in the second half compared to the first half (Trumbo et al., 2017). This demonstrates how passive fatigue can cause increased lane drifting. Increased lane variability occurs as fatigued drivers perform fewer micro lane corrections, and more macro lane corrections (Dawson et al., 2014), as they are slower to respond to the gradual and constant drift that occurs when travelling within lanes.

Another key factor in the driving setting relative to fatigue is reaction time. Reaction time is a valuable proxy measure for driver performance as it is directly relevant to a driver's ability to quickly and thus effectively respond to a changing environment. Reaction time, as measured by psychomotor vigilance task (PVT), is known to increase gradually with increased number of hours awake, with a large spike in reaction time after 24+ hours of wakefulness (Baulk et al., 2006). Increased levels of passive fatigue also influence reaction time. A study examining reaction time of drivers travelling along a simulated highway, found that reaction time increased with the length of time the participants were driving. The road was designed to be as realistic as possible, but to be likened to a monotonous drive with few curves, flat landscape, and low traffic (Ting et al., 2008) suggesting that fatigue may have an adverse effect on reaction time.

The complexities of the impact of fatigue on crashes and work driving safety is further muddled by differences not only in research and definitions associated with fatigue and sleepiness, but also separating the various forms of fatigue. This is important as different forms of fatigue have different causal factors, and thus, require different intervention strategies (May & Baldwin, 2009). As discussed previously, task related fatigue can be distinguished from sleepiness, or sleep related fatigue (Lerman et al., 2012; May & Baldwin, 2009). In the context of driving, task related fatigue can be further separated into passive fatigue and active fatigue. Passive fatigue results from the individual is performing a monotonous drive, an extended drive, or are experiencing cognitive underload, whereas active fatigue results from the individual is performing a secondary task, driving through high-density traffic, or from experiencing increased cognitive load (May & Baldwin, 2009).

Although it may seem counterintuitive, there is evidence that performing secondary tasks, may be beneficial for driver experiencing passive fatigue. When drivers were performing a secondary task in the form of a song naming game, this prevented the decrease in performance associated with performing a monotonous simulated driving scenario. This is explained as despite music potentially acting as a distractor, it was beneficial in instances of cognitive underload (monotonous driving). As this increase in allocation of cognitive resources to the environment, reduced the impact of fatigue (Trumbo et al., 2017).

Separate from the concept of passive and active fatigue, a driver is more likely to experience general fatigue when that driver: Has spent an extended amount of time behind the wheel, is experiencing an elevated mental load, or are driving at certain times of the day (Åkerstedt et al., 2010; Borghini et al., 2014; Trumbo et al., 2017). Employees of the transport industry are likely to experience all of these antecedents. The most ubiquitous likely being spending long periods of time behind the wheel. This is also a key example of passive fatigue. The impact of extended periods of driving can be felt by drivers very quickly. Individuals performing a simulated monotonous driving task began experiencing reduced performance after only 30 minutes in the simulator (Trumbo et al., 2017). This exemplifies the problem of the increased time on task as a contributor to the experience of fatigue. The time of day also has a significant impact on the driver's level of fatigue. This is due to two factors, the driver's experiences a circadian rhythm low resulting in a general feeling of sleepiness, and they likely have already spent a long period of time awake prior to nightfall, resulting in a homeostatic pressure to sleep (Åkerstedt et al., 2010). Together, these neurobiological pressures cause a high level of fatigue, and thus potential for road incidents, for drivers that work at night.

6.0 Monitoring Driver Fatigue

Organisations in attempting to address the substantial risks associated with the monitoring and management of fatigue are looking toward the utilisation of a variety of technology related risk mitigation interventions. The use of technology is growing in popularity, particularly in the heavy vehicle transport and logistics industry wherein transport operations require long-haul activities. For a full review of driver fatigue measurements see May and Baldwin (2009); Sikander and Anwar (2018). Some of the continuous operator monitoring and performance-based monitoring methods are as follows:

- Continuous EEG measurement through electrodes placed on the scalp can signal the transition between wakefulness and sleep.
- Eye closure measurements determine the length of time that eyelids cover more than 80% of the eye. Poorer scores have been associated with higher ratings of sleepiness and longer reaction time.
- Head nodding measurements are performed by technology that focusses on the driver's head and monitors its position, providing a buzz if the head moves into a position similar to the driver falling asleep.
- Lane departure warning systems employ an external camera to monitor the road ahead of the vehicle and can notify the driver when they move outside of the lane bounds.
- Collision avoidance systems in the form of sensors around the outside of the vehicle can notify the driver if they are close to touching obstacles or other vehicles behind or to the side of their vehicle.
- A deadman switch can be installed in a vehicle as a button or switch that the driver must continuously press, if they do not (presumably due to falling asleep), then an alarm is sounded.
- Roadway designs through rumble strips can ensure that noise and vibrations are provided to any driver that veers outside of the normally travelled lanes.

However, while this is encouraging as a means of risk mitigation, challenges still exist associated with the identification of a fatigue related event whereby the driver and subsequently vehicle are not in the close proximity of assistance or even a safe place to immediately pull over. In addition, it is alarming that instances of the use of such technology provides some evidence attesting to how prevalent instances of fatigue are within the work driving setting. Furthermore, while such technology is available, it is currently not mandatory and still requires further development to increase reliability.

7.0 Organisational Culture

Organisational culture is also a very important aspect for any organisation to implement any controls in fatigue safety management. In an Australian organisational setting, a poor organisational safety culture was a large predictor of fatigue related behaviour and fatigue related near misses occurring (Strahan et al., 2008). Employees experience of stress was also a predictor, albeit smaller in strength, of fatigue related incidents (Strahan et al., 2008). Organisational safety culture was measured by a safety climate scale that included items around communication to workers, individuals being able to express their views, enough employees being available, training, and more, and fatigue related behaviour included driving when not had enough sleep, driving for extended periods of time, driving while fatigued, driving longer than 2 hours without breaks (Strahan et al., 2008). Further research into the behaviour of Australian train drivers how beliefs such as feeling that they were unable to be relieved mid-shift would prevent them from stop driving during a shift, no matter how tired they were (Rainbird et al., 2010). In this setting there was a fear of letting the other drivers down (Rainbird et al., 2010). This is transferable to long haul drivers and a potential for a mentality that they “have to” continue driving make their delivery within certain time parameters. Interventions into organisational culture would likely be best suited to being targeted towards management level within the transport industry. Research from Turkey highlighted that when management was perceived to care about safety, there was a negative correlation with safety related violations (Öz et al., 2013).

8.0 Managing Driver Fatigue

Measurement of fatigue is a key aspect in any intervention designed to improve worker or driver safety. However, it is not the first step in mitigating the impact of fatigue. For an organisation to maximise the safety of its drivers, it must ensure that fatigue is measured, reported on, and managed in a proactive manner. Furthermore, the strategies and processes that are implemented to manage fatigue must be applicable to the transport context and the unique organisational context. For the transport industry to be a high reliability industry, it must successfully manage fatigue related safety issues by not only retroactively addressing issues, but also proactively implementing safety systems of hazard identification and mitigation (Gander et al., 2011). In such a maximally safe system, the occurrence of an error would be seen as a failure at multiple levels of hazard identification and mitigation, and an error has a trackable trajectory through these failures (Gander et al., 2011; Reason et al., 2006). However, one of the challenges with fatigue related errors is associated with the real time measurement and monitoring of fatigue and the intervention prior to the actual fatigue event occurring. Recent strides in the realm of continuous measurement of fatigue for road users has made substantial progress in overcoming this challenge. Furthermore, even when organisations have fatigue related measurements and strategies to prevent the occurrence of fatigue related events, there are many factors outside of the organisation’s control which can impact whether an incident occurs. Even with continuous measurement of fatigue, fatigue can still be undetected until the actual error event occurs, which can often be too late when considering the context of an individual operating a vehicle. A number of models developed across safety and other

industries may provide applicable frameworks to explain and manage fatigue within the work driving sector and a brief overview is provided below.

8.1 The Swiss Cheese Model

The Swiss Cheese Model is a model of general safety incident prevention and investigation. The basis of the model is that for a safety incident to occur, breaches of multiple safety defences occurs (Li & Guldenmund, 2018; Reason et al., 2006). A key tenet of the Swiss Cheese Model is that any one breach is not itself a significant failure, or even breaches at multiple levels. Rather, it is when a series of failures occur simultaneously and in an interrelated manner, which allows for a hazard to pass through successive layers of defences to cause an incident (Reason et al., 2006). The levels at which controls can be put in place and failures can subsequently occur include organisational factors, local workplace factors, unsafe acts, and defences (Reason et al., 2006).

8.2 Threat and Error Management

The Threat and Error Management system originated in the aviation industry, but has applicability in a general safety management setting (Brennan et al., 2020; Helmreich, 2000). The model separates threats and errors as two distinct and intersecting avenues that safety incidents can occur through. Threat can either be latent, with organisational culture or professional policies, or they can be immediate with environmental, individual, or team factors (Helmreich, 2000). Errors, when they occur, follow an immediate error management process starting with the error being recognised, and the management of the error state occurring, which can either lead to a negative outcome or the mitigation of the negative outcome (Brennan et al., 2020; Helmreich, 2000). The latent and immediate threats can influence the error management process, with individual and organisational factors influencing whether the error being recognised and how the error state is managed. Despite both the Swiss Cheese Model and Threat and Error Management Model not being explicitly modelled in response to fatigue management, as general models, they are highly applicable to fatigue risk-based management.

8.3 Biomathematical Models of Fatigue Risk Management

Biomathematical model of fatigue employ quantitative methods to predict the level of fatigue that employees experience in association with different working patterns (Dawson et al., 2011). Broadly, such quantitative methods aim to create models of the levels of fatigue that is associated with different shift patterns (James et al., 2018). From there, predictions can be made about the level of fatigue that employees are likely to experience under specific conditions. This should subsequently inform organisational decision-making around shift and work patterns in light of the fatigue-based risk. Example biomathematical models include models where amount of sleep that individuals obtain is measured or their level of opportunity for sleep is measured based on shift scheduling. In either instance, minimum benchmarks are required for an individual to be deemed fit for work (Dawson et al., 2011). Furthermore, biomathematical models have the potential of informing amount of sleep required for safe operation within a specific role to be achieved.

8.4 Safety Error Trajectory Framework

The Safety Error Trajectory Framework created a safety management system focus on modelling the levels of fatigue safety (Dawson et al., 2012; Dawson & McCulloch, 2005). This model recognises the value of past models such as the Swiss Cheese Model and the Threats and Error Management Model while applying it to a fatigue context with the incorporation of the biomathematical models. The model has five levels as follows: opportunity for sleep, actual sleep obtained, symptoms of fatigue,

errors related to fatigue, and the fatigue related error. Each of the levels preceding the fatigue related error describe both where safety failures can occur, or where safety controls can be implemented.

9.0 Adapted Safety Error Trajectory Framework

The below model (see Figure 1) is an adaptation of the Safety Error Trajectory Framework applicable to work driving. The Safety Error Trajectory Framework is an excellent marriage of the focus on sleep and the multi-level safety management models that came before. This adapted version expands on this further and incorporates organisational demands directly into the framework. This allows for an explicit recognition of the significance that the type, importance, and salience that the organisational demands themselves, can have on an employee’s experience of fatigue. Similar to the original framework, each level highlighted below can be understood in regard to both how failures can occur and how controls can be implemented. However, a further expansion in the adapted version below is the discussion of how organisational culture can have a significant impact on both the presence of safety failures and the ability for controls to be implemented.

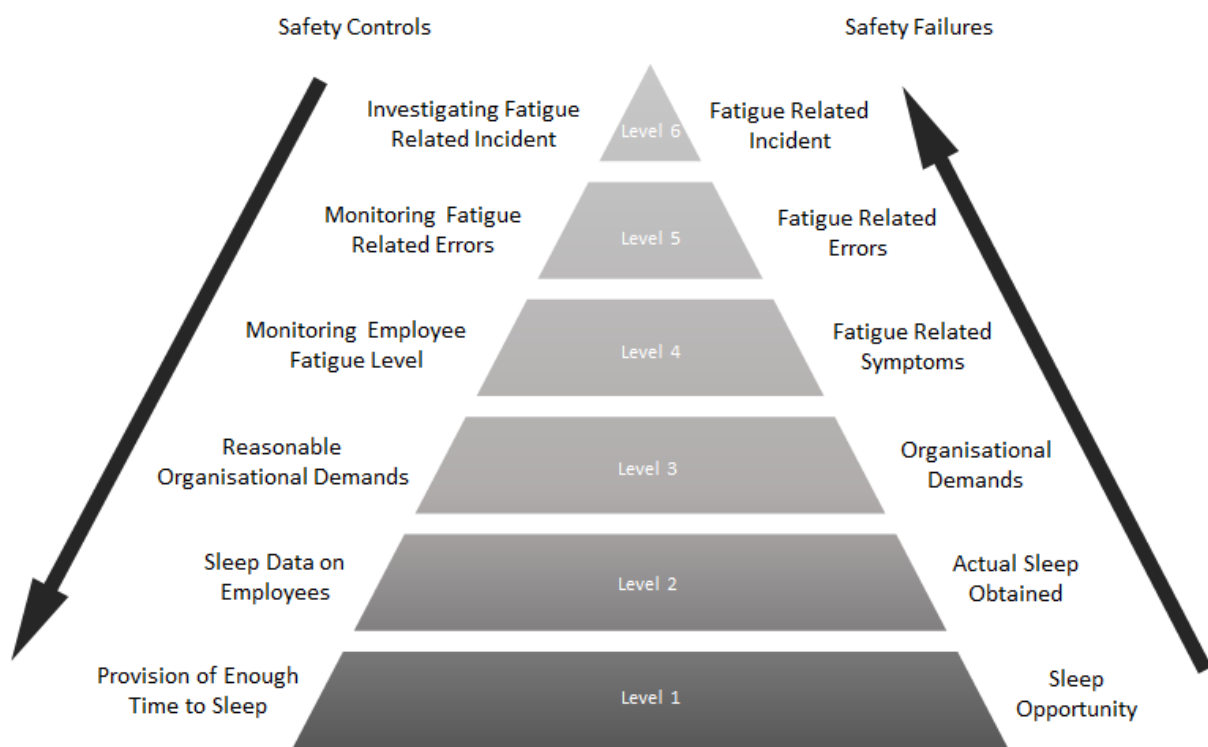


Figure 1: An adapted version of the Safety Error Trajectory Framework with the addition of organisational demands/reasonable organisational demands.

Errors or failures can occur at each level as follows:

- Level 1: This level includes the opportunity that has been afforded to an individual driver to actually sleep. Fundamentally this is a probabilistic assumption as it is not certain that an individual would acquire or be perfectly able to acquire adequate sleep when given a certain period of inter-work time. As such, it is important to note that the average amount of sleep that an individual obtains is relevant here (Dawson & McCulloch, 2005).
- Level 2: This level simply includes the amount of actual sleep that was obtained by the individual. As discussed already in this chapter, amount of sleep obtained, not only in the

past 24-hour period, but longer 48-hour period is relevant for immediate experienced fatigue for drivers (Dawson & McCulloch, 2005).

- Level 3: This level is an expansion of the original Safety Error Trajectory Framework and includes demands that are directly placed on the employees, and the degree to which these are likely to invoke fatigue within the individual. Of relevance here is the types of demands and their presentation to the employees. For instance, the demands could include an individual performing a repetitive and monotonous task at night, such as long-haul driving along straight and flat roads is more likely to experience fatigue (Ting et al., 2008; Trumbo et al., 2017). Alternatively, higher intensity and more cognitively demanding work can produce active fatigue within a driver (May & Baldwin, 2009).
- Level 4: Signs and symptoms of fatigue that the individual displays in their behaviour or cognitive state can indicate their level of fatigue (Dawson et al., 2011). Clear examples of such behavioural indicators include the increased blink frequency and duration.
- Level 5: The occurrence of fatigue related errors. This is the closest step to a safety incident occurring and may have not occurred simply because of other safety barriers, or because the error was not large enough to result in an incident. For instance, a micro-sleep and the associated lane drift while driving would be the occurrence of a fatigue related error; however, it would not necessarily result in a road incident (Dawson et al., 2011).
- Level 6: Occurrence of fatigue related incidents such as a driver being involved in a road incident due to their fatigue.

Controls can be in place at each level as follows:

- Level 1: Organisational controls at this level include ensuring that employees are provided with opportunity to have enough sleep (Dawson & McCulloch, 2005). An example of this would be having a mandatory minimum number of hours between shifts for long-haul workers to ensure that they have had the opportunity to sleep. A further example on long haul is the provision of adequate and suitable areas to sleep.
- Level 2: Organisational controls at this level go beyond ensuring that employees are provided with enough time to sleep, but actually ensuring that they obtain that sleep. This is mostly the responsibility of the individual themselves, as they need to obtain an adequate amount of sleep to function at their maximum capacity. To determine if individuals have had sufficient sleep, prior sleep/wake models can be employed (Dawson & McCulloch, 2005). However, while sleep hours may provide an indication although organisations primarily record the number of hours at rest, further directions could be explored regarding sleep quality.
- Level 3: Organisational controls at this level include ensuring that demands themselves are manageable and realistic. For instance, regulating that workers must have a break after a certain period of time. Furthermore, it would not be conducive to a safe work environment for workers to be presented with demands that require them to work through their breaks, to work overtime, or for them to continue to work even when they feel tired. Managing demands as they are presented to an individual to ensure that drivers delivering products along a timeline have a realistic set of demands set before them can assist as an organisational control.
- Level 4: Measurement is a key component to mitigating the impact of fatigue, and this applies primarily at this level and the next. Level 4 is where the organisation has the opportunity to assess an individual's level of fatigue by measuring the behavioural indicators of fatigue. This is where technology such as eye closure measures, head nodding measurement, and self-report measures of fatigue would be found (Dawson & McCulloch,

2005). Although it is not necessary for these fatigue assessments to take place within the vehicle, many of these measures currently are in the form of continuous operator monitoring such as eye movements as an addition to fitness for duty assessments.

- Level 5: Organisational controls at this level also would include directly monitoring of individuals and the vehicle to measure when close calls occur. Measurements currently utilised within a vehicle are in the form of performance-based monitoring, as it is the fatigue related behaviours that are occurring at this level. Strategies here can expand beyond simply measuring level of fatigue and intervening when fatigue is found, and could attempt to fatigue proof a system that an individual operates within (Dawson & McCulloch, 2005), for instance, automatic warning systems. In comparison to level 4, where the degree to which an individual is experiencing fatigue is measured (e.g. eye closure or head nodding), level 5 would aim to measure the actual errors that result from that fatigue (e.g. lane drift). It must be noted, such errors may not necessarily be resulting in an incident when they are measured.
- Level 6: When fatigue related events do occur, an organisation has an opportunity to investigate the circumstances around the event to determine where the failures occurred in the barriers leading up to that incident. This is for the purpose of continual improvement in the fatigue management system within the organisation.

Organisational culture also directly pertains to the Safety Error Trajectory Framework that is described above at each of the levels as follows:

- Level 1: A negative organisational culture at this level could manifest in how employees and managers treat the minimum time between shifts. For instance, in a health setting, nurses frequently work shifts up to 13-15 hours long while working consecutive days (Trinkoff et al., 2006). This may arise from an industry culture in health care delivery that may be focused on patient care, at the expense of health care professional wellbeing.
- Level 2: At this level an organisational culture exists in the descriptive and injunctive norms that employees perceive around the amount of sleep that is to be obtained between shifts. Despite explicit organisational policy positions on sleep that is to be obtained, employees might not pay much attention to such rules, and instead rely on their perceptions of what is acceptable behaviour, in regards to amount of sleep to be obtained, based on observing the behaviours of others.
- Level 3: At this level an organisational culture may implicitly have demands that extend beyond the explicit deadlines. For instance, it may be procedure that a long haul drive must take a break after a certain amount of time on the road; however, doing so may create a delay in delivery that would not be deemed acceptable for one reason or another.
- Level 4: At this level an organisation culture may not embrace a true safety culture where employees recognise and understand the significance of fatigue. For instance, an organisation can build a safety culture by communicating the priority of driver safety over delivery times through ensuring that all drivers are aware how it is acceptable for them to arrive at their destination late if they need to take a fatigue related break.
- Level 5: At this level an organisational culture can be accepting of errors made by employees. This would encourage a culture where employees feel safe in coming forward with the errors they have made, and not being afraid of punishment, which would encourage them to hide fatigue related errors, potentially leading to an increased likelihood of a fatigue related incident.
- Level 6: At the final stage, once an incident has already occurred, there is a multitude of ways that an organisation can approach the investigation process. If an organisation has

learning culture where safety ideals are truly attempted to be met, then that would have the potential of reducing future incidents with lessons learned. A negative culture around incidents might be purely a liability approach, where the organisation strives to do enough where they would not be financially responsible for any incident, if one does occur.

10.0 Future Directions and Opportunities

In attempting to address the fatigue issue particularly within the work driving context numerous models and risk management frameworks are utilised in conjunction with much laboratory-based research to better understand fatigue and the impact of fatigue on human performance. While fatigue monitoring and management frameworks have improved in recent years, further opportunities and research is required to facilitate continuous improvement and proactive predictability of fatigue events. For instance, the authors are currently involved in conducting pilot research within the heavy vehicle industry sector to investigate real time driver monitoring technology across numerous transport operations and the impact the technology has upon fatigue prevention, driver behaviour and management, and organisational safety culture. Despite the technology providing real time indications of fatigue, monitored drivers still show signs of fatigue related incidents or near misses. Future research and technology directions can hopefully advance to develop reliable mechanisms to determine fatigue well in advance of even these indicators prior to embarking upon a trip.

In addition, fatigue related crashes are potentially under reported. To further advance the determination of fatigue related events, post incident investigations and evaluations into the manner in which fatigue may have interacted with other potential contributing factors needs to be improved.

Organisational safety systems and frameworks need to not only provide adequate structure to mitigate risk and manage fatigue but also need to ensure that they are easily administered and industry friendly in application. Consequently, future research and fatigue framework development within the heavy vehicle sector will require extensive industry consultation and collaboration to ensure that driving fatigue is addressed in a manner that is workable in a competitive business environment along with ensuring other hazards are not introduced into the system.

Finally, while this chapter has focussed on fatigue within the workplace driving setting, there are fatigue and risk management implications associated within other work settings and any advances in managing and mitigating risk within the work driving setting may also provide opportunities to further inform general workplace fatigue.

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