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The application of a proxy measure to estimate the incidence of driver fatigue in Western Australian motor vehicle crashes

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Abstract

This aim of this project was to better understand fatigue as a contributing factor in reported road crashes in Western Australia 2009-2013, particularly those resulting in death or hospitalisation, through the comparative analysis of police reported fatigue-related crashes and fatigue crashes identified from the application of the Australian Transport Safety Bureau (2002) operational definition for fatigue. When the number of fatigue-related crashes was combined from both measures, up to 2% of all reported road crashes for the period may be fatigue-related. The combined proportion is even higher for all reported Killed and Serious Injury crashes (9%) and reported fatal crashes (17.5%). Fewer than one in five crashes rated by police to be fatigue-related were similarly identified from the application of the ATSB definition, though this proportion increased to near 30% when only fatalities were considered. The adjusted annual incidence rates for both police and ATSB identified fatigue-related crashes were found not to vary over the study period. There were many similarities and some differences between the measures in relation to the identification of risk factors for fatigue-related crashes. It was recommended that Western Australia work with national stakeholders to develop a national standardised measure for the assessment and reporting of fatigue to supplement police reports.

Keywords

Fatigue; crashes; measurement; incidence

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EXECUTIVE SUMMARY

Introduction

Driver fatigue is universally regarded as a significant risk factor for crash involvement and injury. Estimates of the contribution of fatigue to crashes vary across jurisdictions and with injury severity, ranging from 2% of road injury fatalities in the USA to 16% of fatal crashes in New South Wales. Most Australian jurisdictions, including Western Australia, do not formally report statistics for the involvement of fatigue in crashes because of concerns over the valid and reliable measurement of the construct. Police who attend crashes often make judgements about fatigue as a contributing factor, as is the case in Western Australia, while others such as New South Wales and Queensland also apply a post-crash proxy of fatigue to supplement the identification of its contribution to crashes. These definitions are a variation of the proxy measure advanced by the Australian Transport Safety Bureau (ATSB) in 2002 (Dobbie, 2002).

The overall aim of the current study was to further understand the contribution of fatigue to motor vehicle crashes in Western Australia, in particular those that result in death and serious injury. The specific objectives of the project were to:

1. Review the published definitions and measurement of fatigue driving and the characteristics and incidence of fatigue-related crashes.
2. Describe the current process in Western Australia for the classification and reporting of crashes as fatigue-related.
3. Estimate the annual incidence and characteristics of fatigue-related crashes in Western Australia based on WA Police reports and the application of the Australian Transport Safety Bureau operational definition for fatigue related crashes.
4. Compare and contrast the findings of the two classification measures.
5. Provide relevant recommendations for the on-going measurement and reporting of fatigue-related crashes and possible countermeasures.

Method

For Objective One, a search of the scientific literature published in Australia and elsewhere, during the years 2000-2016, was undertaken to identify publications relating to the:

1. definition and measurement of fatigue;
2. estimation of fatigue as a contributing factor in crashes, and the,
3. characteristics of fatigue-related crashes and fatigued drivers.

On-line reports from government and non-government agencies were also reviewed to supplement information on the prevalence and characteristics of fatigue-related crashes.

For Objective Two, semi-structured, open-ended interviews were conducted with Western Australian Police (WAPOL) and Main Roads Western Australia (MRWA) to document each agency's contribution to the determination and recording of the involvement of fatigue in crashes.

For Objectives Three and Four, selected motor vehicle crash records were retrieved from the Integrated Road Information Systems (Main Roads Western Australia) for the period 2009-2013. For the analysis of police reports of fatigue involvement the dataset was restricted to only those motor vehicle crashes attended by WA Police and provided with an assessment (Yes *or* No) by police of the contribution of fatigue. Analyses were undertaken to report the incidence and annual rate (*per 100,000 licenced drivers* and *per 100,000 registered vehicles*) of fatigue involved crashes and to calculate the odds of a crash involving fatigue for relevant crash and driver characteristics. These analyses were replicated for ATSB fatigue-related crashes identified from the application of the prescribed operational criteria to the population of all reported motor vehicle crashes for the period. Finally, the correspondence of the two fatigue assessment measures was addressed using the dataset of police attended and fatigue assessed crashes. The analysis focused on the mutual identification of fatigue-related crashes and the factors that potentially affected the level of correspondence.

Summary Results from the Analysis of Motorised Vehicle Crashes

Western Australian Police Assessment and Reporting of Fatigue-Related Crashes

- 36.9% (n=16,741) of all motorised vehicle crashes attended by WA Police 2009-2013 were assessed and rated for fatigue, with no significant variation in the annual proportion of crashes assessed for fatigue over the period.
- 9.8% of all police attended crashes (n=1,644) were judged by attending police to be fatigue-related. This was extrapolated to 0.90% of *all reported crashes*, 6.7% of *all reported fatal crashes* and 4.3% of *all reported hospitalisation crashes* for the period.
- When adjusted for the number of licensed drivers (per 100,000) and registered vehicles (100,000), the incidence rate of fatigue-related crashes for the period was calculated to be 103.65 and 85.95 respectively. Regression analysis showed no significant variation in the annual rates for the period.

- The reporting of fatigue by police was significantly associated with the following crash and driver factors:
    - Fatal crash (19.2%, OR=2.44) and Hospitalisation crash (12.8%, OR=1.50)
    - Killed and Serious Injury crash occurring in Regional Western Australia (19.6%, OR=1.90) and all of Western Australia (13.3%, OR=1.57)
    - Regional WA crash (13.5%, OR=1.86) and particularly the Wheatbelt (21.9%, OR=3.31), the Mid-West Gascoyne (13%, OR=1.75) and South-West WA regions (12.5%, OR=1.68)
    - Single-Vehicle crashes (16.6%, OR=4.03) and the sub-categories of Hit-Object (19.5%, OR=14.16) and Non-Collision/Roll Over (16.2%, OR=11.28) crashes
    - Multiple vehicle head-on collisions (20.2%, OR=14.76)
    - Crashes on curved sections of road (14.3%, OR=1.68)
    - Crashes occurring on 80-90km/hour roads (12.8%, OR=2.61) and ≥100km/hour roads (23.5%, OR=5.50)
    - Crashes occurring 00:00-05:59 (25.3%, OR=3.69)
    - Crashes occurring Sunday (15.3%, OR=1.75) and Saturday (11.5%, OR=1.26)
    - Male driver involved in single vehicle crashes (17.3%, OR=1.23)
    - Drivers involved in a single vehicle crash aged ≥20 years (ranging from 15.1% to 20.5%, OR=1.37 to OR=2.0)
    - Drivers involved in a single vehicle crash with a BAC 0.001-0.0499 (23%, OR=1.53)

Australian Transport Safety Bureau Identified Fatigue-Related Crashes

- n=2,498 crashes or 1.3% of *all reported crashes* for the period 2009-2013 were identified as fatigue-related, equating to 12.7% of *all reported fatal crashes* and 4.9% of *all reported hospitalisation crashes*.
- When adjusted for the number of licensed drivers (per 100,000) and registered vehicles (100,000), the incidence rate of fatigue-related crashes for the period was calculated to be 157.50 and 130.60 respectively. Regression analysis showed no significant variation in the annual rates for the period.
- The identification of fatigue-related crashes from the application of the ATSB definition was significantly associated with the following crash and driver factors:
    - Fatal crash (12.7%, OR=13.16) and Hospitalisation crash (4.9%, OR=4.67).

- Killed and Serious Injury crashes occurring in Metropolitan Perth (2.1%, OR=4.57), Regional WA (12.3%, OR=2.91), and all of Western Australia (5.5%, OR=5.28)
- Regional WA crash (5.5%, OR=10.4) and particularly the Wheatbelt (11.8%, OR=23.9) and Mid-West Gascoyne regions (7%, OR=13.5)
- Crashes on curved sections of road (2.6%, OR=2.36)
- Crashes occurring on ≥100km/hour roads (13%, OR=2.32)
- Multiple vehicle crashes occurring midnight to 6.00am (OR=3.06) and 2.00pm to 4.00pm (OR=1.98)
- Crashes occurring Sunday (2.5%, OR=1.88) and Saturday (1.8%, OR=1.37)
- Drivers of trucks (9.1%, OR=1.41) and heavy vehicles (14.9%, OR=2.48) involved in a single vehicle crash
- Drivers aged ≥25 years (ranging 7.1% to 9%, OR=1.27 to OR=1.64) involved in a single vehicle crash

Correspondence analysis

- Based on the analysis of the n=1,644 police attended crashes assessed for fatigue, 9.8% were judged by police to be fatigue-related compared with 4.8% from the application of the ATSB operational definition.
- n=265 crashes were identified by both police and the ATSB definition to be fatigue-related, representing approximately 16.1% of crashes reported by police to involve fatigue.
- n=14,551 crashes were identified by both police and the ATSB definition to *not involve fatigue*, representing approximately 96.4% of crashes assessed by police *not to be* fatigue-related.
- Correspondence in the identification of fatigue-related crashes:
  - increased to 27.3% for fatal crashes and 20.5% of hospitalisation crashes reported by police to involve fatigue.
  - increased to 22.3% for crashes occurring in Regional WA and reduced to 10.3% crashes occurring in Metropolitan Perth (10.3%) reported by police to involve fatigue.
- Of the n=1,379 crashes reported by police to be fatigue-related but not identified by the application of the ATSB operational definition, alcohol, speed zone, and single-vehicle

crashes occurring outside critical event times accounted for most of the excluded fatigue-related crashes as per operational criteria.

Summary and Recommendations

This research has identified that around a third of *all police attended crashes* and a similar proportion of *all recorded KSI* crashes for the period 2009-2013 included a report by police on the involvement of fatigue. The adjusted annual incidence of fatigue for both police reports and the application of the ATSB definition were found not to have significantly varied over this time. When the number of fatigue-related crashes identified from both measures is combined, up to 2% of *all reported crashes* for the period may be fatigue-related. The combined proportion is even higher for *all reported KSI crashes* (9%) and *all reported fatal crashes* (17.5%). These proportions vary somewhat with those reported elsewhere in Australia and New Zealand. A comparison of the findings of the analysis of police reported fatigue crashes and ATSB defined fatigue crashes showed that fewer than one in five crashes judged by police to be fatigue-related were similarly identified from the application of the ATSB definition. However, the correspondence was increased to nearly 30% for fatal crashes and to 20% for those occurring in Regional WA. This suggests that the proxy measure might be more relevant and applicable for this level of crash severity, particularly if it occurs in the non-metropolitan region. The findings also highlight the need to revise the proxy measure to make it more inclusive of fatigue-related crashes that occur at other high risk times, in lower speed zones, and involve other crash types.

The crash and driver characteristics identified from the analysis of police reports and the application of the ATSB definition also suggested a level of comparability between the measures to identify risk factors for fatigue that were generally supportive of those identified from a review of the literatures. From both measures, the reporting and identification of fatigue was significantly and reasonably consistent in relation to the injury severity of the crash, the region, speed zone and time of day of the crash, and the crash type. There was however, less consistent evidence across the measures for the risk of a fatigue-related crash associated with driver sex and age and vehicle type.

The findings of this investigation suggest a number of possible recommendations:

1. *That Western Australian Police investigate the range of factors that might be contributing to the low level of assessment of fatigue by officers who attend traffic crashes.*

2. *That Western Australia collaborates with national stakeholders to develop a national, standardised definition for the measurement and reporting of fatigue as a contributing factor in crashes, and that this measure be applied post-crash to supplement the reporting of fatigue by police.*
3. *That further research is undertaken of select serious injury fatigue-related crashes to investigate their relationship with road infrastructure factors, particularly in high risk regional locations such as the Wheatbelt*

ACKNOWLEDGEMENTS

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1. INTRODUCTION

Driver inattention is a noted risk factor for crash involvement and resulting injury (Beanland, Fitzharris, Young, Lenne, 2013). Of the various causes of inattention, there has been considerable focus on the driver state labelled as 'fatigue' though sometimes interchangeably referred to as 'drowsiness', 'sleepiness' or 'tiredness'(Connor, 2009; May, 2011; Phillips, 2015; Shen, Barbera & Shapiro, 2006). Fatigue has been described as a hypothetical construct and is defined by the biological drive for recuperative rest; it may not be directly observable but can produce measurable, observable effects (Williamson, Lombardi, Folkard, Stutts, Courtney & Connor, 2011). Fatigue is considered to impact on the likelihood of a driver committing an error, the magnitude of errors committed, and the variability of the errors (Jackson et al., 2011) which together can increase the risk of crashing (Dobbie, 2002; Jackson, Hilditch, Holmes, Reed, Merat & Smith, 2011; Williamson, et al., 2011).

Worryingly, 'fatigued' or 'sleepy-drowsy' driving is relatively commonplace, especially among certain driver groups such as long distance truck drivers (Jackson et al., 2011; Zhang & Chan, 2014) and younger age drivers (Jackson et al., 2011). Community surveys of *self-reported* 'fatigued or 'sleepy-drowsy' driving (without crashing) have produced varying estimates, ranging from 11% of US drivers (Tefft, 2010) to 25% of French drivers (Sagaspe et al., 2010) in the preceding 12-months, and 69% in the preceding five years for a sample of over 1,500 Australian drivers (Watling, Armstrong & Radun, 2015).

Despite fatigue being widely acknowledged as a contributing factor in crashes, there is limited evidence from population-based investigations to quantify the magnitude of the problem, particularly in Australia. The government agencies of only two jurisdictions – New South Wales (NSW) and Queensland (QLD) – report annual statistics for fatigue-related crashes based on defined criteria in conjunction with information from police. In NSW, fatigue was considered to be a contributing factor in approximately 16.5% of fatal crashes, 8.7% of non-fatal injury crashes, and 10% of non-injury crashes occurring in 2014 (NSW Centre for Road Safety, 2015). In contrast, fatigue was judged to be a contributing factor in approximately 11.5% of fatal crashes in Qld in 2015 (Transport and Main Roads Queensland, 2016).

Elsewhere, the National Highway and Safety Administration report that ‘fatigue’ and ‘drowsy driving’ was a contributing factor in up to 2.6% of fatalities in the USA for 2014 (http://www.nhtsa.gov/Driving+Safety/Drowsy+Driving/Research+on+Drowsy+Driving). This percentage is considerably lower than the 15%-30% of fatal crashes reported for Finland (Kilpelainen, Radun & Summala, 2005) and 13% of fatal crashes reported in New Zealand (New Zealand Ministry of Transport, 2015).

Estimating the incidence of fatigue among crash involved drivers is problematic because of the absence of objective, measureable biological evidence of the type which is available when considering other potential causes of driver impairment and inattention such as alcohol or illicit drugs (Radun & Radun, 2009). At present there appears to be no universally accepted, standardised operational definition to support the valid and reliable determination of fatigue among crash involved drivers (May, 2011; Phillips, 2015; Williamson et al., 2011).

While most jurisdictions appear to rely on the assessments undertaken by attending police to determine the involvement of fatigue, researchers and some road safety agencies have attempted to construct and apply a proxy measure to supplement the assessments made by police to better estimate the involvement of fatigue in crashes. In Australia, the most notable of the published proxy measures is the operational definition proposed by the Australian Transport Safety Bureau (ATSB) (Dobbie, 2002). This proxy definition has been used in modified ways by New South Wales and Queensland transport agencies. The respective proxy measures are reviewed in Section 3.3.

Western Australia, like many other Australian jurisdictions, does not formally report on the involvement of fatigue in crashes despite recording information on the assessment of fatigue in a crash made by attending police. Unfortunately, however, a high proportion of crashes attended by WA Police lack information on the involvement of fatigue. A preliminary analysis conducted for this study of crashes 2009-2013 resulting in death or hospitalisation showed that information on the contribution of fatigue was missing for around seven in 10 crashes. Consequently, our understanding of the contribution of fatigue to the most serious of all reported crashes in Western Australia is likely to be inadequate and incomplete.

1.1 Aims and objectives

The overall aim of this study is to further understand the contribution of fatigue to motor vehicle crashes in Western Australia, in particular those that result in death and serious injury. The specific objectives of the project are to:

1. Review the published definitions and measurement of fatigue driving and the characteristics and incidence of fatigue-related crashes.
2. Describe the current process in Western Australia for the classification and reporting of crashes as fatigue-related.
3. Estimate the annual incidence and characteristics of fatigue-related crashes in Western Australia based on WA Police reports and the application of the ATSB operational definition for fatigue.
4. Compare and contrast the findings of the two classification measures.
5. Provide relevant recommendations for the on-going measurement and reporting of fatigue-related crashes and possible countermeasures.

2. METHOD

2.1 Ethics approval

This research was undertaken with the approval of the Human Research Ethics Committee, Curtin University; approval number RDHS-114-16 (10th May 2016).

2.2 Study Design

This study was undertaken in three parts. Firstly, a review of the published literature on fatigue was undertaken (Section 2.3 and Section 3); secondly, interviews were conducted with local road safety stakeholders responsible for the assessment and recording of fatigue in crashes (Section 2.4 and Section 4) and thirdly, data on crashes occurring in Western Australia were used for the retrospective analysis of fatigue reported by Western Australian Police and from the application of the Australian Transport Safety Bureau's operational criteria for fatigue (Sections 2.5 to 2.63 and Sections 5 and 6).

2.3 Literature search and retrieval

A search of the scientific literature published in Australia and elsewhere from 2000-2016 and on-line government and non-government publications was undertaken to identify information relating to the:

- definition and measurement of fatigue;
- estimation of fatigue as a contributing factor in crashes, and the,
- characteristics of fatigue-related crashes and fatigued drivers

Key or seminal papers published prior to 2000 were also considered. Key words (e.g., 'fatigue driving'; 'drowsy driving'; 'sleepy driving') were used to search databases such as Google scholar, ProQuest, and PsychInfo to retrieve local, national and international publications (books, reports, scientific journal articles, conferences papers).

2.4 Interviews with Western Australia Police and Main Roads Western Australia personnel

Semi-structured, open-ended interviews were conducted with Western Australian Police (WAPOL) and Main Roads Western Australia (MRWA) to document each agency's contribution to the determination and recording of the involvement of fatigue in crashes. Select personnel from *State Traffic Command*; *Major Crash*

Investigation Section, and the *Traffic Policy Unit* of WAPOL were interviewed regarding the processes and operations involved in the attendance of crashes and the determination of driver fatigue by police as a contributing factor. From MRWA, personnel from *Planning and Technical Services* and the *Road Safety* sections were interviewed regarding the interpretation of police crash reports and the subsequent recording of WAPOL fatigue reporting in Integrated Road Information System (IRIS) database of reported crashes (see Section 2.4).

2.5 Western Australian Crash Data

De-identified records of motor vehicle crashes (both *police attended/reported* and *road user reported*) occurring during the period 2009-2013 in Western Australia on gazetted public roads were extracted from Integrated Road Information System (IRIS) and supplied by MRWA. Crashes occurring prior to 2009 and after 2013 were not considered due to the absence of sufficient, recorded information on the assessment by attending police of the involvement of fatigue (indicated as a *Yes* or *No* response) and secondly, existing concerns over the completeness and accuracy of hospitalisation crash records in IRIS for the period 2014-2015. It should be noted that information on the contribution or otherwise of fatigue is recorded as a *crash level factor* based on the assessment by police of individual drivers. This means that the fatigue status of a given *driver* can be determined in the case of a single vehicle crash but not in the case of a multiple vehicle crash involving multiple drivers.

2.6 Data management and analysis

De-identified crash data for the period 2009-2013 were received from MRWA in multiple CSV format files and subsequently transferred into SPSS (Ver. 22). After aggregation of the data files, the following driver-vehicle inclusion criteria were applied. Only crashes involving the following motorised vehicle types were included:

- Motorcars and derivatives
- Buses
- Motorcycles and derivatives
- All classes of trucks and heavy vehicles

2.6.1 Selection and analysis of crashes assessed by Western Australian Police for the involvement of fatigue

For the analysis of police reported fatigue the crash dataset was restricted to include only those crashes which were:

- attended by police, and
- were assessed by police for the involvement of fatigue (recorded as *Yes* or *No*).

Descriptive analyses were undertaken to determine the annual proportion and rate (*per 10,000 licenced drivers* and *per 10,000 registered vehicles*) of fatigue-related crashes. Univariate analyses were also undertaken to describe the characteristics of fatigue-related crashes and crashing drivers and the associated odds (using Binary Logistic Regression) for fatigue involvement. The findings of these analyses were descriptively compared with those based on the application of ATSB operational definition.

2.6.2 Selection and analysis of crashes based on the application of the Australian Transport Safety Bureau operational definition for the involvement of fatigue

ATSB fatigue-related crashes were identified from the application of the prescribed exclusion and inclusion criteria reported in Dobbie (2002) to the restricted dataset of all reported crashes. Crashes were excluded from consideration if they:

- occurred on a road with a posted speed limit below 80km/hour

  OR
- involved collision with a pedestrian

  OR
- involved a driver who had no authority (e.g., unlicensed) to drive at the time of the crash

  OR
- the driver returned a Blood Alcohol Concentration level ≥ 0.05gm%

Following these exclusions, crash records were categorised as fatigue-related if the circumstances of the crash met the following inclusion criteria:

- a single vehicle crash occurring between midnight-6.00am or 2.00pm-4.00pm

  OR

- a head-on crash in which neither of the involved vehicles was overtaking at the time of the crash

Reported crashes that were excluded or did not meet the inclusion criteria for a crash were designated to be non-fatigue crashes.

Descriptive analyses were undertaken to determine the annual proportion and rate (*per 100,000 licenced drivers* and *per 100,000 registered vehicles*) of ATSB defined fatigue-related crashes. Univariate analyses were also undertaken to describe the characteristics of fatigue-related crashes and crashing drivers and the associated odds (using Binary Logistic Regression) for fatigue involvement. The findings of these analyses were descriptively compared with those based on the police assessment of attended crashes.

2.6.3 Correspondence Analysis

The correspondence of the two fatigue assessments methods (i.e., WAPOL and ATSB) was investigated through an examination of crashes which were attended by police and assessed for fatigue (as per 2.5.1). The fatigue status of each crash record was categorised in one of four ways:

- Mutual agreement as a *fatigue-related* crash
- Mutual agreement as a *non-fatigue related* crash
- Police defined *fatigue-related* crash; ATSB defined *non-fatigue* related crash
- ATSB defined *fatigue-related* crash; police defined *non-fatigue* related crash

The analysis focused on the mutual identification of fatigue-related crashes and the identification of factors that potentially affected the level of correspondence.

3. LITERATURE REVIEW

This Chapter presents a summarised review of the published and 'grey literature' on fatigue and driving and fatigue-related crashes. The review commences with a summary of the issues regarding the definition and causes of fatigue. This is followed by a review of the characteristics of fatigued drivers, their behaviours, and fatigue-related crashes. The review concludes with a discussion of the use of proxy measures to estimate the incidence of fatigue among crash involved drivers.

3.1 Defining fatigue and its causal factors

Defining fatigue and distinguishing it from associated states such as sleepiness and drowsiness has been the subject of considerable debate in the research literature. At the core of the construct is a subjective feeling state which may be expressed as 'tiredness' and the need for recuperative rest (i.e., sleep) (Phillips, 2015). However, the condition is complex and represents more than just a tendency to 'fall asleep' (Chipman & Jin, 2009). The level of fatigue a driver might be experiencing cannot be directly measured but the effects of being fatigued are readily identifiable in the driving context through the measurement of direct indices of driving performance (e.g., steering control and lane keeping; speed compliance) and associated perceptual and cognitive functioning (Williamson, Freyer & Friswell, 1996). In broad terms, fatigued drivers show decreased attention and alertness; their reaction times are slowed as is their information processing, and their decision making deteriorates as they are less able to process and integrate relevant information (National Highway Transportation Safety Administration, 2000).

Excessive stimulation or workload is central to the concept of fatigue but alone does not adequately explain how fatigue can occur (Phillips, 2015). Phillips (2015) argues that both individual and environmental factors may mitigate or exacerbate the effects of task demands. These factors can include the individual's rest and sleep history and wake-rest circadian rhythm status; the personal value placed on the performance of the task at hand, and the individual's personality traits and health status to manage task demands (Philips, 2015). Together, these factors are presumed to influence the development of fatigue and the associated decrement in cognitive and behavioural functioning on tasks that require alertness, attention, decision making, and physical manipulation (Philips, 2015).

Of the aforementioned ‘causal’ factors, considerable research has focussed on the role of task and sleep-related factors. As depicted in Figure 3.1, these factors are proposed to have an independent and interactive effect on the development of fatigue and the subsequent effect on driver performance and crash risk (May, 2011; May & Baldwin, 2009; Williamson et al., 2011).

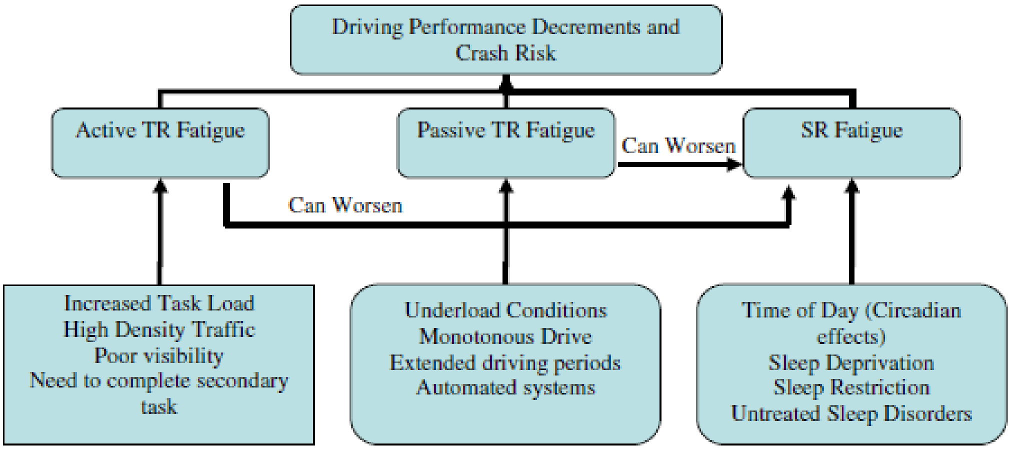

Figure 3.1 Model of Fatigue

(Source: May and Baldwin, 2009)

As depicted in Figure 3.1, the driving task is proposed to be a cause of fatigue if it either overloads (Active Task Related Fatigue) or under stimulates (Passive Task Related Fatigue) the driver in relation to demands (May & Baldwin, 2009). Of the various Active-Task related factors, ‘time on task’ (e.g., time spent driving) can be a significant cause of fatigue and is often used a proxy exposure measure when investigating adverse outcomes such as crashes (Williamson et al., 2011). However, the relationship between ‘time on task’ and adverse outcomes such as crashes or other safety failures in industry can be modified or confounded by factors such as the time of day the task commenced and the individual’s preceding sleep pattern (Williamson et al., 2011).

These findings highlight how task and sleep related factors can interact to cause fatigue and performance decrements. Other Active-Task related factors that may contribute to driver fatigue include how adverse the driving conditions are (e.g., weather) and having to complete multiple tasks while driving (May & Baldwin, 2009). Situations such as adverse driving conditions will likely require sustained and prolonged attention and vigilance which research has highlighted to be a significant cause of performance decrement over time (Williamson et al., 2011).

In contrast to high task demands, May and Baldwin (2009) propose that drivers will become passively fatigued and inattentive if the driving task is monotonous and under-stimulating. This position is supported by the findings of the review by Williamson et al. (2011) of performance outcomes and task demands which concluded that under stimulating environments and monotonous tasks were equally as likely to cause performance decrements. As an example, in such situations drivers have been known to exhibit an increased number of steering over-corrections and increased lane weaving (May & Baldwin, 2009).

In keeping with a multidimensional model of fatigue, the driver's wake-rest status and sleep related health conditions may also contribute to the development of Sleep-Related Fatigue either directly or indirectly by undermining the driver's capacity to deal with the task demands of driving (May & Baldwin, 2009). This relationship is in the first instance influenced by the homeostatic and circadian rhythm processes that regulate the human sleep-wake drive cycle. Homeostatic control means that individuals who have had prolonged periods of wakefulness will find it difficult (without stimulants) to resist the urge to sleep; their sleepiness will increase and their ability to effectively undertake driving tasks will progressively diminish (Connor, 2009). To exemplify this, Lenne, Triggs and Redman (1998) found that participants' performance (e.g., lane position; speed, reaction time) on a repetitive simulated driving task declined and/or deteriorated when drivers were sleep deprived and were required to complete a secondary task. Employing a similar simulator based methodology and additional reaction-time tasks, Johns, Chapman, Crowley and Tucker (2008) found that driver-subjects who were sleep deprived for 27-33 hours displayed increased reaction times, a higher incidence of failure to respond, and an increased incidence of 'drive off road' events. In addition to these objectively measured decrements in performance, research has shown that subjects' self-ratings of fatigue are "..higher with higher levels of sleep restriction.." (Ferguson, Paech, Sargent, Darwent, Kennaway & Roach, 2012, page 53).

In addition, the known periods of decreased wakefulness under the control of two distinct biological rhythms means that individuals will feel an increased propensity for sleep in the middle of the afternoon and then again between 2.00am and 5.00am (Connor, 2009). These periods, particularly the latter, have been found to be associated with poorer cognitive and motor skills performance on driving related tasks (Monk, Weitzman,, Fookson, Moline, Kronauer & Gander, 1983) and increased risk of crash involvement, particularly for the early morning period (Folkard, 1997). In the model proposed by May and Baldwin (2009), driving task demands may prove more or less demanding, and hence fatiguing, at these times of the day which may be exacerbated further by the driver's preceding poor sleep history. Indeed the research by Williamson and Friswell (2011) demonstrated an interactive effect of time of day and sleep deprivation, but not independent main effects, on subjective ratings of fatigue and performance on a number of (non-driving) computer based tests concerned with vigilance; reaction time; tracking; memory; coding; searching, and reasoning.

The model proposed by May and Baldwin (2009) also posits that undiagnosed clinical sleep disorders can contribute to driver fatigue. Indeed there is good evidence to show that conditions like Obstructive Sleep Apnoea (OSA) that result in day-time sleepiness (Jordan, McSharry & Malhortra, 2014) can increase a driver's risk of crash involvement. A systematic review and meta-analysis of studies investigating OSA and crash involvement found that private and commercial drivers with OSA were 1.2 to 4.8 times more likely to crash than those without OSA (Treager, Reston, Schoelles, & Phillips, 2009).Consistent with these findings, the population based case-control investigation of heavy vehicle drivers in Western Australia by Meuleners and Fraser (2012) noted that OSA significantly increased the odds of being involved in a crash by a factor of three. The most recent meta-analysis and systematic review of studies investigating sleepiness and crash risk amongst professional drivers (e.g, truck and heavy vehicle drivers) similarly confirmed significantly higher odds of crash involvement for conditions such as sleep apnoea (1.75), excessive daytime sleepiness (1.89) and acute sleepiness (1.85) (Zhang & Chan, 2014). However, the case-control study by Stevenson et al. (2014) of non-fatal crash involved heavy vehicle drivers in New South Wales did not find that drivers with OSA had a significantly higher risk of crash involvement.

The relationship between clinical sleep disorders like OSA and crash involvement highlights the concern that some authors have regarding sleepiness/drowsiness and fatigue as independent risk factors for crash involvement (Johns et al., 2008). While May and Baldwin (2009) postulate that clinical sleep disorders are a cause of fatigue, others authors such as Johns (2000) propose that sleepiness linked to conditions such as OSA does not necessarily mean that drivers will be fatigued per se because they may doze "..off while driving, soon after a night's sleep, without any sense of fatigue" (page 243). From this perspective, these drivers are not necessarily fatigued but sleepy.

To summarise, the terms fatigue, sleepiness, and drowsiness are frequently used interchangeably to refer to the condition where drivers feel tired and become less attentive and cognitively adept and able to exercise appropriate behavioural control over driving tasks. In relation to the causes of fatigue, researchers have highlighted the role of the driving task itself and the surrounding environment which may either overly tax or under-stimulate the driver. It has also been proposed that a drivers' sleep or wake-rest history and circadian rhythm variations in wakefulness may directly cause or exacerbate the demands of the driving task to create a fatigue state. Lastly, clinical sleep disorders such as OSA may cause daytime sleepiness and increase crash risk, though some authors consider this condition to be separate and distinct from fatigue per se. In conclusion, it would seem that task and sleep factors share a complex relationship in the development of fatigue and resulting performance decrements. Consequently, neither factor should be considered in isolation of the other when considering relevant countermeasures to manage fatigue.

3.2 The characteristics of fatigued-related crashes and drivers

There is a large body of research describing the characteristics and risk factors for fatigue-related driving and crash involvement. In most cases this information has been derived from the analysis of crash records where fatigue has been reported by police or a coronial investigation, and in some cases the application of a proxy or surrogate measure. The most significant and consistently identified crash and driver factors are summarised in the sections below.

3.2.1 Crash Factors

Type of Crash

Fatigue-related crashes are reportedly best defined and characterised by the type of crash. Single vehicle run off road, loss of control crashes and head-on collisions not involving an overtaking manoeuvre are most commonly reported to be fatigue-related (Dobbie, 2002). Early research involving the review of coronial records of Australian fatalities noted that approximately 75% and 22% of collisions identified to be fatigue-related were single vehicle and head-on collisions respectively (Haworth & Rechnitzer, 1993). The over-representation of fatigue in single vehicle, run off road crashes has since been noted in a number of investigations. A Finnish investigation of drivers who crashed during the period 2004-2005 and were subsequently charged with 'driving whilst tired' reported that 81% of charged drivers were involved in a single vehicle run off road collision and 5.9% in a head-on collision (with no information reported about overtaking). In the United States, Tefft's (2012) investigation of crashes of varying severities (i.e., not just fatalities) occurring during the period 1999-2008 found that 13.4% of all single vehicle crashes involved a 'drowsy' driver compared with just 1.9% of multiple vehicle crashes, with 28% of 'road departure' (e.g., run off road) crashes involving fatigue compared with 2.4% for other crash types. In Australia, a smaller but in-depth crash investigation study by Hatfield, Friswell and Williamson (2015) of 15 drivers involved in a fatigue-related crash and admitted to hospital in New South Wales during the period 2010-2013 found that fatigue case crashes were more likely to be single vehicle in nature and to have run off the road and collided with an object compared with non-fatigue crashes. In contrast to previous studies, head-on crashes were not found to be over-represented among the fatigue case study crashes investigated. Most recently, New Zealand Transport (2015) reported that 99% of fatal crashes occurring 2012-2014 identified to be fatigue-related were single vehicle, loss of control and head-on crashes.

In summary, single vehicle run off road, loss of control and head on crashes (particularly those that do not involve overtaking) are consistent with the characterisation of fatigued and sleepy drivers as having diminished capacity to maintain motor control over their vehicle or to effect corrections in the event of a lane departure.

Crash Severity

For the most part fatigue-related crashes have been investigated in relation to fatal crashes only. Consequently there is limited information on the contribution of fatigue to the full range of crash severities such as non-fatal injury (i.e., hospitalisations) and non-injury (i.e., property damage only) crashes. Notwithstanding this limitation the available evidence suggests that a higher percentage of fatal crashes are judged to involve fatigue compared with crashes that result in a non-serious injury or no injury. For example, fatigue was twice as likely to be reported for crashes involving a fatality (16.5%) compared with a non-fatal injury (8.7%) crash in New South Wales. Further to this, around one in ten non-injury crashes in New South Wales were judged to involve fatigue (NSW Centre for Road Safety, 2015). These figures are somewhat comparable with those reported for crashes occurring in New Zealand during the period 2012-2014, where fatigue was twice as likely to be reported for crashes resulting in a fatality (13%) compared with a serious (6%) or a minor (6%) injury (New Zealand Ministry of Transport, 2105).

Time of Day

As discussed, previous research has provided varying evidence to show that fatigue or sleep-related crashes are more likely to occur during two distinct time periods which approximate the known circadian rhythm periods of reduced wakefulness (Connor, 2009; Dobbie, 2002; Williamson et al., 2011). The early work of Pack, Pack, Rodgman, Cucchiara, Dinges and Schwab (1995) and Folkard (1997) noted that crashes most likely to be judged as fatigue-related occurred after midnight and before dawn and then again in the early afternoon. Analysing the time periods traditionally associated with the circadian rhythm effects, Chipman and Jin (2009) reported that 4.5% and 9.7% of severe injury single vehicle crashes in Ontario in the years 1999-2004 during the periods 2.00pm-4.00pm and 2.00am-5.00am involved fatigue compared with 2.8% and 2.1% for crashes occurring 10.0am-12noon and 9.00pm-11.00pm respectively. This pattern was similarly observed for fatal and serious injury crashes occurring 2012-2014 in New Zealand, where the percentage of police reported fatigue-related crashes peaked during the periods 3.00am-5.00am and 3.00pm-5.00pm (New Zealand Ministry of Transport, 2015).

Other investigations have been less than definitive and supportive of the relationship between time of day, fatigue and crash involvement. This is partly due to variations in the time periods analysed. In their analysis of crashes occurring 2000-2006 in Queensland, Armstrong, Smith, Steinhard and Haworth (2008) noted that 51% of 732 fatigue/sleep-related crashes occurred in the period 10.00pm-6.00am compared with 12.1% of 317 non-fatigue related crashes. For the afternoon period, 2.00pm-4.00pm, there was evidence to the contrary of a circadian rhythm effect: 7.2% fatigue/sleep related crashes versus 14.8% for non-fatigue/sleep related crashes. The lack of evidence of an afternoon circadian rhythm effect may be due to this study's focus on lower speed urban area only crashes.

Radun and Radun's (2009) study of Finnish drivers charged with 'driving whilst tired' 2004-2005 was broadly supportive of the relationship between time of day and a fatigue crash. They reported that that the majority of crash involved offenders were apprehended between 1.00am and 8.00am and 3.00pm and 6.00pm than at any other time of day. Interestingly, the authors noted a significant interaction between time of day of offence and driver sex, with older drivers more likely to be apprehended during the afternoon while younger drivers were more likely to be apprehended at night. Differences between the two age groups in driving exposure and lifestyle may account for the variation in offence times.

Employing even broader time periods, Tefft (2012) reported that a higher proportion of crashes in the USA occurring 11.00pm-6.59am (15.6%) compared with 7.00am-10.59pm (2.4%) involved a drowsy driver. While the in-depth case study by Hatfield et al. (2015) considered very few cases (n=15), there was some evidence to support a time of day/circadian rhythm effect: around 13.4% of fatigue case crashes occurred 12.00am-5.59am compared with 2.6% of comparison cases, while 53% of fatigue case crashes occurred 12.00pm-5.59pm compared with 42% of comparison cases.

In conclusion, fatigue or sleep related crashes can occur at any time of day. However, the research evidence is generally supportive of a peak in fatigue and sleep related crashes in the early hours of the morning followed by another, lesser peak mid-afternoon. These time periods roughly align with the known circadian rhythm changes of reduced wakefulness and alertness at these times. It should be noted however, that extended periods of wakefulness may also be a contributing factor along with circadian rhythm changes to early morning crashes (Williamson et al., 2011).

Road Type and Speed Zone

Early analyses of coronial records identified that fatigue-related crashes were most likely to occur on high speed highways located in rural areas compared with lower speed roads in urban areas (Haworth & Rechnitzer, 1993). This fact goes some way to explaining why fatigue-related crashes typically result in more severe injury outcome (New Zealand Ministry of Transport, 2015). Over the years a number of studies have provided broad support for this early finding and as well as evidence of the involvement of fatigue on lower speed roads. For example, Tefft's (2012) analysis of US crashes 1999-2008 noted that crashes occurring in the 50-55 mph/80-88kmh (5.8%) and 60+mph/96+kmh (10.5%) evidenced the highest proportion of fatigue-related crashes. In his study of crash involved Finnish drivers who were judged to have fallen asleep, Radun (2009) reported that such drivers were 17 times more likely to have crashed on a main road compared with a street (though no information was presented regarding the speed limits of these roads).

Other research has identified the involvement of fatigue in crashes on lower speed, urban area roads. Armstrong et al's. (2008) investigation of crashes occurring 2000-2006 on New South Wales roads with a speed limit up to and including 60kmh noted that around 1% was reported to involved fatigue. In contrast, 2.1% of all crashes in the same period, irrespective of speed zone, were judged to involve fatigue. Similarly, the in-depth case investigation conducted by Hatfield et al. (2015), though small in number, noted the involvement of fatigue in crashes on lower speed roads. The authors found an equal distribution of fatigue-related crashes on roads speed zoned up to and including 80kmh and above 80kmh. However, the ratio of fatigue-related crashes to non-fatigue related crashes in the latter speed zone category was 3:1.

In conclusion, higher speeds zones appear to be associated with an increased risk of crashing whilst fatigued though there is evidence that such crashes also occur in lower speed zones. The higher incidence of fatigue crashes on roads with higher speed zones may be due to the fact that these zones are typically associated with non-urban area driving which may involve trips of a longer and potentially fatiguing duration (Dobbie, 2002).

3.2.2 Driver Factors

Driver Demographics: Age and Sex

Driver age and sex can be readily analysed from crash reports to investigate their relationship with fatigue-related crashes. However, the understanding of these demographics as risk factors is thought to be confounded by their association with differences in key fatigue-related exposure factors such as time of day of driving, driving experience, hours of work, and occupation (Di Millia, Smolensky, Costa, Howarth, Ohayon & Philip, 2011). This information is not readily available in large scale crash datasets and as such, their relationship with fatigue driving is yet to be established.

Age

In relation to age, researchers have suggested that younger age drivers have a higher risk of being fatigued whilst driving because of their late night driving patterns and propensity for 'general fatigue' due to poor sleep patterns (Williams, 2003). Indeed, there is some evidence from the analysis of large-scale crash datasets to suggest that younger age drivers are more likely to be involved in fatigue-related crashes. Tefft's (2012) analysis of US crashes 1999-2008 showed that fatigue was most frequently identified among crashing drivers aged 16-24 (5.2%) and 25-39 years (4.3%) compared with those aged 40-59 (2.9%) and 60+ years (3.1%). Age was similarly found to be significantly associated with fatigue for crashes in Queensland 2000-2006 on lower speed roads (Armstrong et al., 2008). In the study, drivers aged 17-24 years were more likely to be involved in fatigue-related crashes compared with older age drivers. In addition, a greater proportion of provisionally licenced drivers – who are predominantly younger age persons – featured in fatigue related crashes (28.1%) compared with non-fatigue related crashes (19.5%).

Further evidence of the relationship between driver age and fatigue-related crash involvement was provided by Mitchell, Senserrick, Bambach & Mattos (2015) from their comparative analysis of provisional and full licence holder police reported crashes in New South Wales 2001-2011. The authors found that a significantly greater proportion of novice driver crashes (those aged 17-25 years) involved fatigue compared with older age driver crashes. The authors also noted the fatigue as a crash risk factor did not necessarily occur independently of other contributing factors such as alcohol and speed.

Driver age was also found to be strongly and consistently associated with the involvement in fatigue/sleep-related crashes occurring on high speed roads (≥100kmh) in Queensland, 2000-2009 (Filtness et al., 2015). Using both police and the Queensland Department of Transport proxy measure of fatigue, the authors found that both measures identified a significantly higher incidence of fatigue among younger age and provisionally licensed drivers who crashed (compared with older and full licence holders).

In contrast to preceding findings, a somewhat different pattern of age involvement was reported for fatigue-related fatal crashes occurring in New Zealand, 2012-2014. Drivers aged 60+ years (38%) accounted for the highest proportion of fatigued drivers, followed by those aged 15-24 years (25%) (New Zealand Ministry of Transport, 2015).

In conclusion, there is some population based evidence to show that fatigue is more likely to be a contributing factor in the crashes of younger age and provisionally licensed drivers compared with older age drivers. This could be due however, to their well-known pattern of late night driving (Williams, 2003) and perhaps their lack of driving experience and expertise to compensate when driving skills begin to decline through fatigue (Di Millia et al., 2011).

Sex

Notwithstanding the aforementioned factors that confound the relationship between driver sex and the involvement in fatigue-related crashes, some research has identified that male drivers are more likely to be involved in fatigue-related crashes. Tefft (2012) reported that slightly higher proportion of male driver crashes (5%) compared with female drivers crashes (3%) involved fatigue. A similar trend was noted by Armstrong et al. (2008) who found that male drivers were three times more likely than females to be involved in fatigue-related crashes though only twice as likely as females to be involved in non-fatigue related crashes.

The over-representation of males was even greater in the studies by Radun and Radun’s (2009) and Filtness et al., (2015). In the former study of Finnish drivers who crashed and were charged with ‘driving whilst tired’, nearly 81% of offenders were male, with the difference between the sexes greatest among drivers under 30 years of age. Similarly, Filtness et al. (2015) reported that males accounted for 75% to 78.5% of fatigue crashes - depending on the process of assessing fatigue (police versus QLD Transport proxy definition).

As per the finding for driver age, the New Zealand population based study of crashes 2012-2014 did not support earlier findings for male drivers but instead showed that fatigue was a contributing factor in proportionally more crashes involving female drivers (12%) than male drivers (8%) (New Zealand Ministry of Transport, 2015).

Driver Status: Commercial-Heavy Vehicle Drivers

Considerable attention has been devoted to the risk of fatigue among commercial or heavy vehicle drivers. Such drivers are thought to be at higher risk of a fatigue related crash because of their particular working conditions. These conditions include driving long distances under monotonous conditions (Jackson et al., 2011); working to irregular schedules and operating under time pressures and work practices that promote fatigue driving (May, 2011; Williamson et al., 1996); driving during periods of reduced wakefulness (Jackson et al, 2011; Meuleners, Fraser, Govorko & Stevenson, 2015; Stevenson et al., 2013), having limited opportunities for extended, quality sleep prior to driving (Arnold, Hartley, Corry, Hochstadt, Penna & Freya, 1996; May, 2011) or breaks between driving (Stevenson, et al., 2013; Meuleners et al., 2015), and being compromised by medical conditions such as sleep apnoea and excessive daytime sleepiness (Jackson et al., 2011).

The role of work practices in the development of fatigue is a particular concern as identified above and most recently by the research of Williamson and Friswell (2013) from a cross-sectional survey of heavy vehicle drivers in New South Wales. Among the many findings, the authors reported that longer working hours and greater distances driven were significantly associated with higher levels of self-reported fatigue. They also noted that drivers were more likely to report a higher level of fatigue on their last trip if they were required to wait and were not paid for waiting; had less driving experience, and had fewer hours rest before the trip.

Unsurprisingly, fatigue has been identified as a significant factor in the crashes of heavy vehicle drivers. The analysis of Australian fatality data from 1990-1998 employing the Australian Transport Safety Bureau definition of fatigue (see Section 3.3.1) indeed found that the contribution of fatigue in fatal crashes involving articulated trucks was double that for fatal crashes involving all other vehicle types for each year of the period (Dobbie, 2002). Furthermore, nearly six in ten articulated truck fatal crashes occurred in the 12-hour period covering midnight-6.00am and midday-6.00pm.

3.3 The use of surrogate or proxy measures for the identification of fatigue

As previously stated, there is widespread agreement that the contribution of fatigue and sleepiness in crashes is likely to be underestimated (Dobbie, 2002). This is firstly due to difficulties with the valid and reliable operationalisation and measurement of these constructs among crash involved drivers (Dobbie, 2002; Filtness et al., 2015), and secondly, the nature of crashes and their investigation by police (Dobbie, 2002). In regards to the latter, investigating police are frequently unable to interview a surviving driver or witnesses, particularly in single vehicle crashes, to determine the possible involvement of fatigue. Even when there are survivors who can be interviewed they may be less than forthcoming about the involvement of fatigue or sleepiness because of the threat of prosecution (Dobbie, 2002; Radun, Ohisalo, Wahde & Kecklund, 2013). Consequently, attending police must consider the nature and circumstances of the crash (e.g., single or multi vehicle; run off road; the involvement of impairing substances and potential sources of distraction) and other information about the driver (e.g., work and rest history; emotional and mental state) derived from non-crash sources (e.g., family members, friends, employers) to establish a case for the contribution of fatigue. This process may be undermined by the fact that not all attending or investigating police will have received the necessary training to reliably and validly undertake this task (Radun et al., 2013).

To overcome the preceding limitations researchers and government agencies alike have attempted to construct and apply evidence-based, objective proxy measures based on research findings across sleep and road crash studies – such as those reviewed in the preceding section - to better estimate the incidence of fatigue in crashes. This process has its origins in the early works of Horne and Reyner (1995) and the US government Expert Panel on Driver Fatigue and Sleepiness (EPDFS) (1997). These works were subsequently extended by Dobbie (2002) to develop an operational definition of fatigue that could be applied across Australia. The operational definition is reviewed in Section 3.3.1 below as background for the application to crashes occurring in Western Australia 2009-2013.

Though a standardised assessment process for fatigue has to date not been adopted across Australia, both Queensland and New South Wales apply their own post-crash proxy measures to police crash reports to increase the detection of fatigue-related crashes (Armstrong et al., 2013). These are similar in some ways to the aforementioned ATSB operational definition and are briefly reviewed in Section 3.3.2

3.3.1 Australian Transport Safety Bureau Operational Definition

The operational definition of fatigue developed by the Australian Transport Safety Bureau (Dobbie, 2002) adopted some of the earlier criteria presented by Horney and Reyner (1995) and the EPDFS (1997) as well as others employed elsewhere in Australia. The definition includes:

- Single vehicle crashes that occurred during ‘critical times’ (midnight-6.00am and 2.00pm-4.00pm)
- Head-on collisions where neither vehicle was overtaking at the time

(Dobbie, 2002, page 7)

The definition also excludes crashes that:

- Occurred on roads with speed limits under 80km/hour
- Involved pedestrians
- Involved unlicensed drivers
- Involved drivers with high levels of alcohol (blood alcohol over 0.05g/100ml

(Dobbie, 2002, page 7)

As noted in the definition, and from the preceding literature review, the type of crash and the time at which it occurred are central to the identification of a crash as being fatigue-related. By excluding other known risk factors for crashing such as alcohol and unlicensed driving, this measure is intended to identify fatigue as a primary but not contributing crash factor. This exclusion may indeed underestimate fatigue as a contributing factor since other studies have noted the co-occurrence of fatigue and illegal levels of alcohol among crash involved drivers (Filtness et al., 2015) and the incidence of fatigue among unlicensed crashing drivers (Armstrong et al., 2008). Further to this, the exclusion of crashes occurring on roads speed zoned under 80kmh will likely exclude those fatigue-related crashes on road with posted speed limits up to 60kmh more recently identified by Armstrong et al. (2008).

The initial application of the ATSB operational definition was undertaken by Dobbie (2002) using fatality file data for 1990, 1992, 1994, 1996, 1997 and 1998. Fatigue information in these files was based on police and coronial investigations.
Across the period, the ATSB definition identified that between 14.9% and 18% fatal crashes to involve fatigue. The rate per 100,000 population was highest among drivers aged 17-24 and 25-29 years and males, across both single vehicle run off road crashes and head on crashes (not involving overtaking), findings which are generally supported by more recent research reviewed in the preceding section.

Of particular interest was the level of agreement between police and the operational definition regarding the involvement of fatigue. Dobbie's (2002) analysis of this for fatalities occurring in 1998 showed reasonably high agreement for fatalities *not involving fatigue* but less agreement on *fatalities involving fatigue* (Table 3.1). The operational definition identified around 205 fatalities that police and coronial reports excluded fatigue as a contributing factor, largely because these crashes were judged by police to involve driver errors, drugs and/or alcohol, excessive speed and other unspecified factors. Further analysis by Dobbie (2002) revealed that police judged fatigue to be a contributing factor in crashes outside of the identified critical times, involving unlicensed drivers, and occurring on roads with a posted speed limit below 80kmh –crashes that the operational definition excluded as involving fatigue. He subsequently concluded that that the time inclusion criteria for single vehicle crashed could be extended as this had been a significant source of disagreement between the identification of fatigue crashes by police/coroners and the operational definition. This would seem warranted if the definition is to remain dynamic and receptive to changes in driving and exposure (such as those associated with the moved toward a 24-hour work and leisure society in Australia).

Table 3.1 Matching decisions made by coroners/police and the operational definition in relation to the identification of fatigue involvement in fatal crashes, Australia, 1998

Coroner/Police identification of fatigue involvement in a fatal crash	Operational definition identification of fatigue involvement in a fatal crash					
	No Fatigue		Fatigue		Total	
	n	%	n	%	n	%

No Fatigue	1207	85.5	205	14.5	1,412	100
Fatigue	53	53.5	46	46.5	99	100
All Fatalities	**1,260**	**100**	**251**	**100**	**1,511**	**100**

Adapted from Dobbie (2002, Table 7 page 19)

Dobbie (2002) concluded that the operational definition was not intended to be an absolute measure of fatigue as a contributing factor in crashes but should serve as a guide for the selection of and use of rules for the identification of fatigue in crashes. Research applications of the ATSB operational definition

There has been limited investigation and application of the ATSB operational definition since its release in 2002. Only two published studies could be identified for this review, neither of which utilised a population based methodology to assess the utility of the definition.

In the first study by Crummy et al. (2008), the ATSB definition was judged against information obtained from a detailed questionnaire/interview with a sample of 40 crash involved Victorian drivers who were hospitalised. The interview/questionnaire specifically examined the presence of acute and chronic sleepiness, circadian rhythm disturbances, and symptoms suggestive of sleep disordered breathing and other sleep disorders. It was reported that only 25% of crashing drivers whom clinicians deemed to have been involved in a sleep-related crash (from the information obtained by questionnaire/interview) were judged by the ATSB definition to be fatigued.

The second study by Armstrong et al. (2011; 2013), sought to determine the relevance and utility of the ATSB definition using a community based survey of drivers in New South Wales and the Australian Capital Territory. From a sample of some 1,609 drivers, only 37 (2.3%) reported having been involved in fatigue-related crash. No information was provided for the severity of the crash. Based on the information about the time and nature of crash, the authors concluded that the ATSB definition was less than applicable. Some 40% of the self-reported fatigue-related crashes occurred on roads under 80kmh; with roughly four in ten crashes fitting the description of a single vehicle, run off road crash. The details of these crashes, particularly the reported involvement of fatigue, were not verified.

Unfortunately, neither study employed a research methodology which provides sufficient opportunity and information to investigate the applicability and utility of the ATSB definition. As such, there is a need to further investigate the contemporary utility of the ATSB definition and to make recommendations for the revision of the inclusion and exclusion criteria to support the identification of fatigue-related crashes by attending police and to further our understanding of drivers and circumstances that present an increased risk for a fatigue-related crash.

3.3.2 Proxy measures used by Queensland and New South Wales

The post-crash proxy measure applied by the Department of Transport and Main Roads, Queensland, to support the assessment of fatigue made by attending police officers differs from the aforementioned ATSB operational definition in regards to the speed zone of the crash, the time of day of the crash type, the type of crashes considered, and the involvement of other high crash risk behaviours. Filtness et al. (2015 page 2) writes that the proxy measure identifies 'sleepiness' as a *contributing* (and not primary causal) factor in crashes when the crash:

- Is a single-vehicle collision and occurs in ≥100km/hour speed zones between the hours of 2.00pm-4.00pm and 10.00pm-6.00am, or,
- Where the vehicle leaves the roadway with the driver not attempting to avoid the crash

This operational definition differs from the ATSB version in that it extends the night-time hours to 10.00pm for a single vehicle crash; it excludes single vehicle crashes occurring on roads with a posted speed limit greater than or equal to 80km/hour but less than 100km/hour, and does not specifically identify head-on collisions (without overtaking) but instead includes run off road crashes where there is an absence of evidence to suggest the driver attempted to regain control. Further to this, the definition does not exclude crashes involving alcohol or unlicensed drivers.

A recent study by Filtness et al. (2015) which compared the fatigue assessments of police and the QLD Transport proxy definition applied to crashes occurring in 100kmh zones during the period 2000-2009 found that the proportion of fatigued-related using the proxy measure was around three times greater than that identified by attending police: 14.9% *versus* 5.3%. The authors concluded with a warning that neither method provided a validated means to accurately identify fatigue.

In New South Wales, the criteria used to identify fatigue as a *contributing factor* is somewhat less prescriptive than either the ATSB or Queensland definitions. The New South Wales Centre for Road Safety (2016 page 8) states that in addition to police determining that the driver or rider was asleep or drowsy or tired, the driver is deemed to be fatigued if any of the following occurs:

- The vehicle travelled onto the incorrect side of a straight road and had a head-on collision (and was not overtaking another vehicle and no other relevant factor was found), or,
- The vehicle ran off a straight road or off the road to the outside of a curve and the vehicle was not travelling at excessive speed and there was no other relevant factor found

Whilst this definition specifically includes head-on collisions it does not specifically include or exclude crashes based on speed zone or time of day. It is implied however, that behavioural risk factors such as unlicensed driving and excessive alcohol or excessive speeding may result in discounting fatigue as a contributing factor. In this sense the New South Wales and the ATSB definitions are similar and different to the Queensland definition regarding the identification of fatigue as a contributing factor when other known crash risk factors (e.g., speed, alcohol, unlicensed driving) can be determined.

4. THE ASSESSMENT AND RECORDING OF FATIGUE IN CRASHES IN WESTERN AUSTRALIA

Semi-structured open-ended interviews and other correspondence were conducted with key personnel from Western Australian Police and Main Roads Western Australia to document the key issues in the assessment and recording of fatigue for crash involved drivers. The information presented below is a summary of these interviews and other correspondence with the agencies.

4.1 Western Australian Police

Assessments of the contribution of fatigue to crashes is the province of WA Police, in particular, the officers who attend the crash and other officers who conduct follow up assessments of the crash scene and investigations with surviving drivers. The assessment of fatigue as a primary or contributing factor by police precedes the official reporting of the factor for uploading to the Integrated Road Information System (see information below on the 1-18 report form). However, there are no records of specific methods for the investigation of contributing factors.

When there is no surviving driver WA Police will examine the crash scene and the vehicle to understand the movement of the vehicle, the level of driver input during the crash incident, and any recorded vehicle data that may indicate what was occurring prior to the crash, such as steering, braking and acceleration. The movement of the vehicle is considered to be an "indicator" that raises the possibility of fatigue, but may also indicate a medical episode or distraction (eyes off the road). Police will also interview witnesses who may have observed the vehicle prior to or during the crash and also interview other (surviving) occupants of the vehicle to solicit information about contributing factors. Interviews may also be conducted with persons who knew the driver's movements and behaviour prior to driving to establish whether sleep deprivation or factors such as medications or other substances may have contributed to fatigue.

Thus, WA Police will investigate the circumstances of the crash and collect evidence as to the causation. In any court proceedings or Coroners Report, the evidence presented is determined by either the Criminal Courts or the Coroner who will make their findings. Any conclusion drawn by police investigators outside of the court or Coroner's processes will be based on what the evidence points to or is consistent with. Where witness accounts and admissions are consistent with the vehicle and scene evidence police will be satisfied fatigue was the main factor. However, often the lesser weight of evidence in some incidents may indicate a "consistent with" conclusion where distraction or medical episode (blacked out) cannot be ruled out. Judgements by the coroner regarding the involvement of fatigue will be updated in police records and crash reports.

In the case of a surviving driver, *certain drivers* (i.e., those who may be subject to prosecution) will be subject to an 'open-ended' questionnaire based interview to 'profile' the likely occurrence of fatigue or other factors as a cause of the crash. This may be undertaken if police are considering charges against the surviving driver. In all, there are 99 questions covering areas such regular sleep patterns, sleep on previous night and two nights, sleep disorders, subjective sleepiness during the drive, interactions with passengers, and details of the drive. There are also specific sections for Shift-Workers and Drivers of commercial vehicles. In other circumstances, police who attend the crash will otherwise note fatigue as a potential contributing factor (Yes or No) via the 1-18 First Attendance Police Crash report which is provided to Main Roads Western Australia for uploading to IRIS.

4.2 Main Roads Western Australia

The role of Main Roads Western Australia is to transcribe crash information provided by police to populate the dataset of reported crashes in IRIS. Unless fatigue or its non-involvement is specifically noted by police in reports provided to MRWA, their data entry operators will not otherwise interpret or attempt to logically deduce the role of fatigue as a contributing factor from other crash information. Nor does MRWA formally apply a post-crash proxy measure to supplement the assessment and facilitate the official reporting of fatigue as a contributing crash factor. Finally, no information on fatigue is provided via the Online Crash Reporting Facility (the self-report crash system) from which MRWA also draws crash records.

5. THE INCIDENCE AND CHARACTERISTICS OF POLICE REPORTED FATIGUE IN WESTERN AUSTRALIAN CRASHES 2009-2013

Based on the vehicle inclusion criteria presented in Section 2.5 a total of 186,585 motorised vehicle crashes were recorded in IRIS for the period of investigation (Table 5.1). Of this number, 45,375 (24.3%) crashes were recorded as being police attended. A total of 16,741 crashes (36.9%) were provided with an assessment by police on the involvement of fatigue, of which 3,561 were killed or serious injury (hospitalisation) (KSI) crashes. This equated to 33.6% of all reported KSI crashes.

Table 5.1 Number of reported, police attended, and fatigue assessed motor vehicle crashes and involved drivers; Western Australia 2009-2013

Crash Status	Crashes
All Reported	**186,585**
Fatal	822
Hospitalised	9,784
Medical Treatment/Property Damage Only	175,977
Police Attended	**45,375**
Assessed for Fatigue	16,741
Fatal	*286*
Hospitalised	*3,275*
Medical Treatment/Property Damage Only	*13,180*

n=2 missing crash severity for all reported crashes

The number of crashes with a fatigue assessment remained relatively stable over the period of investigation (Table 5.2), with no significant variation over time in the annual proportion of police attended crashes with a fatigue assessment (β=0.08; t=0.15, p=.885).

Table 5.2 Annual number and proportion of police attended motor vehicle crashes assessed for fatigue; Western Australia 2009-2013

Year	Assessed for Fatigue		Percentage of All Police Attended Crashes
	n	%	
2009	3,248	19.4	38.1
2010	3,100	18.5	34.5
2011	3,499	20.9	37.1
2012	3,652	21.8	37.7
2013	3,242	19.4	36.9
All Years	**16,741**	**100**	**36.9**

Across the period of investigation only 9.8% (n=1,644) of crashes assessed for fatigue were reported to involve fatigue. This number represents approximately 0.90% of *all reported crashes* for the period 2009-2013. The proportion of crashes judged by police to involve a fatigued driver did not significantly vary over the period of investigation (β=0.080; t=0.405, p= .712).

Table 5.3 Annual frequency distribution of fatigue for police attended motor vehicle crashes; Western Australia 2009-2013

	Crash Level Fatigue					
	Yes		**No**		**Total**	
Year	**n**	**%**	**n**	**%**	**n**	**%**
2009	301	9.3	2,947	90.7	3,248	100
2010	325	10.5	2,775	89.5	3,100	100
2011	324	9.3	3,175	90.7	3,499	100
2012	375	10.3	3,277	89.7	3,652	100
2013	319	9.8	2,923	90.2	3,242	100
All Years	**1,644**	**9.8**	**15,097**	**90.2**	**16,741**	**100**

The annual incidence was subsequently adjusted for potential changes over time in the number of licensed drivers and registered vehicles. The rate for the period per 100,000 licensed drivers was calculated to be 103.65 (95%CI 98.64-108.66) while the rate per 100,000 registered vehicles was calculated to be 85.95 (95%CI 81.80-90.10). Linear regression of the annual rates (Figure 5.1) showed no statistically significant variation in the incidence of fatigue-related crashes over time.

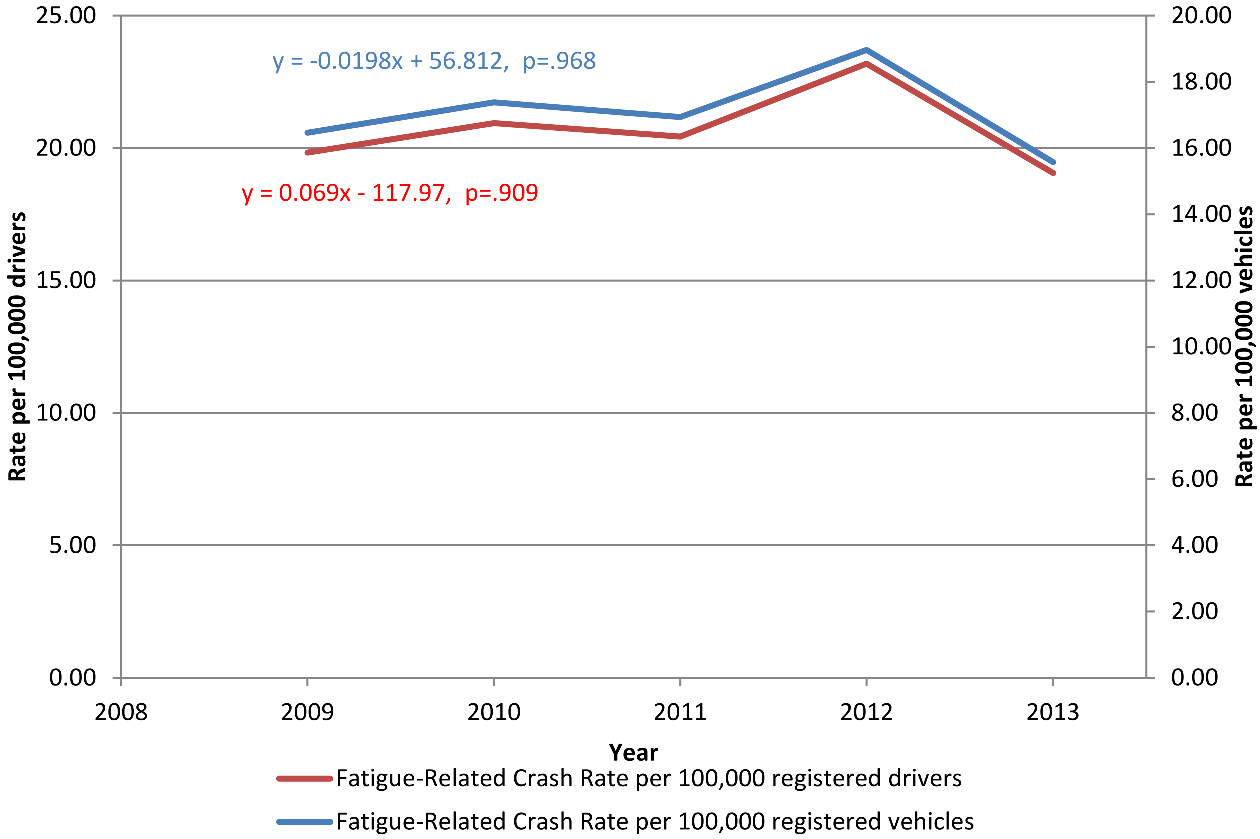

Figure 5.1 Annual rate of police reported fatigue-related crashes per 100,000 registered drivers and per 100,000 registered vehicles; Western Australia 2009-2013

5.1 Crash, Environment and Temporal Characteristics of Fatigue-Related Crashes

5.1.1 Injury Severity

Approximately 71% of police attended crashes judged to involve fatigue resulted in medical treatment or property damage only (MT/PDO). The number of fatigue-related fatal (n=55) and hospitalisation (n=419) crashes represented 6.7% and 4.3% of *all recorded fatal and all recorded hospitalisation* crashes respectively for the period.

The judged incidence of fatigue was highest for crashes that resulted in a fatality (19.2%) or a hospitalisation (12.8%) compared with MT/PDO (8.9%) crashes. Compared with the latter group of crashes, police were significantly more likely to assess the crash as fatigue-related when it resulted in a hospitalisation - 1.5 times more likely - (OR=1.55 95%CI 1.38-1.75) or fatality - 2.5 times more likely - (OR=2.44 95%CI 1.81-3.30).

Table 5.4 Frequency and odds of fatigue for police attended motor vehicle crashes; by injury severity of the crash, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		**No**		**Total**				
Crash Severity	n	%	n	%	n	%	**OR**	**95%CI**	**p**
MT/PDO^	1,170	8.9	12,010	91.1	13,180	100	1.00	-	-
Hospitalisation	419	12.8	2,856	87.2	3,275	100	1.50	1.33-1.69	.000
Fatality	55	19.2	231	80.8	286	100	2.44	1.81-3.30	.000
All	**1,644**	**9.8**	**15,097**	**90.2**	**16,741**	**100**			

MT-PDO: Medical Treatment or Property Damage Only. ^Reference group for calculation of OR. Model X^2 66.78, df=2, p=0.000

The relationship between the injury severity of the crash and police reporting of fatigue was examined further in relation to the region of the crash (Table 5.5). For this analysis fatal and hospitalisation crashes were grouped as Killed and Serious Injury (KSI). There were distinct differences across the regions in regard to the incidence of judged fatigue among KSI and non-KSI crashes. In Metropolitan Perth, the proportion of KSI (8.7%) and non-KSI (7.6%) crashes reported to involve fatigue was similar; thus there was no significant difference in the odds of fatigue for crashes of varying injury severity (OR=1.11 95%CI 0.94-1.33). In contrast, the incidence of fatigue was proportionally higher among KSI crashes in both Regional WA (19.6% *versus* 11.3%) and all of Western Australia (13.3% *versus* 8.9%). Thus, crashes resulting in death or hospitalisation (KSI) increased the odds of the crash being judged by police to involve fatigue by 57% in all of Western Australia (OR=1.57 95%CI 1.40-1.76) and nearly two-fold in Regional WA (OR=1.90 95%CI 1.62-2.22).

Table 5.5 Frequency and odds of a fatigue-related police attended motor vehicle crash; by region and injury severity of the crash, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		No		Total				
Region/Severity	n	%	n	%	n	%	**OR**	**95%CI**	**p**
Metro Perth									
Non-KSI^	673	7.7	8,122	92.4	8,795	100	1.0	-	-
KSI	171	8.5	1,842	91.5	2,013	100	1.11	0.94-1.33	.204
All	**844**	**7.8**	**9,964**	**92.2**	**10,808**	**100**			
Regional WA									
Non-KSI^	497	11.3	3,888	88.7	4,385	100	1.0	-	-
KSI	303	19.6	1,245	80.4	1,548	100	1.90	1.62-2.22	.000
All	**800**	**13.5**	**5,133**	**86.5**	**5,933**	**100**			
All of WA									
Non-KSI^	1,170	8.9	12,010	91.1	13,180	100	1.0	-	-
KSI	474	13.3	3,087	86.7	3,561	100	1.57	1.40-1.76	.000
All	**1,644**	**9.8**	**15,097**	**90.2**	**16,741**	**100**			

^Reference group for calculation of OR. KSI: Killed or Seriously Injured. *Metro Perth Model* X^2 1.58, df=1, p=.208; *Regional WA Model* X^2 62.32, df=1, p=.000; *All of WA Model* X^2 58.22, df=1, p=.000

5.1.2 Region

The number of crashes judged to be fatigue-related was near evenly distributed across Metropolitan Perth and Regional WA (Table 5.6), though the incidence of police reported fatigue was higher in Regional WA (13.5%) compared with Metropolitan Perth (7.8%). Crashes in Regional WA were nearly twice (OR=1.86 95%CI 1.68-2.05) as likely as those in Metropolitan Perth to be reported by police as fatigue-related.

Table 5.6 Frequency and odds of fatigue for police attended motor vehicle crashes; by region of crash, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		No		Total				
Crash Region	n	%	n	%	n	%	**OR**	**95%CI**	**p**
Metro Perth^	844	7.8	9,964	92.2	10,808	100	1.00	-	-
Regional WA	800	13.5	5,133	86.5	5,933	100	1.86	1.68-2.05	.000
All	**1,644**	**9.8**	**15,097**	**90.2**	**16,741**	**100**			

^Reference group for calculation of OR. Model X^2 134.22, df=1, p=0.000

Further analysis of the data categorised by the Main Roads WA region of the crash (Table 5.7) showed that the odds of a police reported fatigue-related crash was significantly higher in all MRWA non-metropolitan regional areas - with the exception of the Great Southern - when compared with Metropolitan Perth. The most problematic non-metropolitan regional areas for fatigue-related crashes - based on the frequency of occurrence and the size of the increased odds – were the Wheatbelt (OR=3.31 95%CI 2.79-3.91) and the South-West regions (OR=1.68 95%CI 1.46-1.94). These two areas represented 19.8% of all police attended crashes assessed for fatigue in WA but accounted for 30.7% of all fatigue-related crashes.

Table 5.7 Frequency and odds of fatigue for police attended motor vehicle crashes; by Main Roads WA region, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		**No**		**Total**				
MRWA Region	n	%	n	%	n	%	**OR**	**95%CI**	**p**
Metropolitan Perth^	844	7.8	9,964	92.2	10,808	100	1.00	-	-
Goldfields-Esperance	67	11.7	507	88.3	574	100	1.56	1.19-2.03	.001
Great Southern	48	8.3	531	91.7	579	100	1.06	0.78-1.44	.675
Kimberley	43	12.6	298	87.4	341	100	1.70	1.22-2.36	.001
Mid West Gascoyne	90	13.0	604	87.0	694	100	1.75	1.39-2.21	.000
Pilbara	46	11.0	374	89.0	420	100	1.45	1.06-1.98	.020
South-West	296	12.5	2,070	87.5	2,366	100	1.68	1.46-1.94	.000
Wheatbelt	210	21.9	794	78.1	959	100	3.31	2.79-3.91	.000
All	**1,644**	**9.8**	**15,097**	**90.2**	**16,741**	**100**			

^Reference group for calculation of OR. Model X^2 206.30, df=7, p=.000

5.1.3 Crash Type

The relationship between crash type and fatigue was investigated in relation to the number of vehicles involved (single *versus* multiple vehicles) and the specific nature of the crash. It is clear from Table 5.8 that the majority of police reported fatigue-related crashes were single vehicle in nature. This crash type represented around 43% of all police attended crashes with a fatigue assessment but accounted for 73% of all fatigue-related crashes. Police were four times (OR=4.05 95%CI 3.59-4.51) more likely to report the involvement of fatigue for a single vehicle crash (16.5%) compared with a multiple vehicle crash (4.7%).

Table 5.8 Frequency and odds of fatigue for police attended motor vehicle crashes; by crash type and nature, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		**No**		**Total**				
Crash Type/Nature	n	%	n	%	n	%	**OR**	**95%CI**	**p**
Multiple *vs* Single									
Multiple^	443	4.7	9,025	95.3	9,468	100	-	-	-
Single	1,201	16.5	6,072	83.5	7,273	100	4.03	3.59-4.51	.000
All	1,644	9.9	15,097	90.2	16,741	100			
Nature									
Right Turn Thru^	29	1.7	1,691	98.3	1,720	100	1.0	-	-
Hit Pedestrian	14	2.0	670	98.0	684	100	1.21	0.64-2.32	.548
Hit Animal	6	2.3	256	97.7	262	100	1.36	0.56-3.32	.491
Right Angle	96	3.1	2,982	96.9	3,078	100	1.87	1.23-2.85	.003
Sideswipe (SD)	40	4.7	820	95.3	860	100	2.84	1.75-4.62	.000
Rear-End	124	5.1	2,314	94.9	2,438	100	3.12	2.07-4.70	.000
Non Collision	245	16.2	1,266	83.8	1,511	100	11.28	7.62-16.69	.000
Hit Object	982	19.5	4,043	80.5	5,025	100	14.16	9.74-20.57	.000
Head On	78	20.2	308	79.8	386	100	14.76	9.48-23.0	.000
All	**1,614**	**10.1**	**14,350**	**89.9**	**15,964**	**100**			

N=777 crashes with missing Nature value. SD: same direction ^Reference group for calculation of OR. Multi/Single Model X^2 655.79, df=1, p=.000. Nature Model X^2 1,117.16, df=8, p=.000

In relation to the specific nature of the crash, fatigue was more commonly reported by police for single vehicle run off road crashes such as those resulting in a roll over (non-collision, 16.2%) or hit-object (19.5%). These crash types accounted for three in ten crashes attended and assessed by police for fatigue but represented over seven in ten crashes judged to be fatigue-related. Single vehicle run off road crashes were 11 (O=11.28 95%CI 7.62-16.69) to 14 (O=14.16 95%CI 9.74-20.57) times more likely than right turn thru crashes to involve fatigue. In addition to these crash types, around one in five (20.2%) multiple vehicle head-on collisions were judged to involve fatigue with a calculated odds ratio of 14.76 (95%CI 9.48-23.0).

5.1.4 Road Alignment

The alignment of the road (i.e., straight or curved) was found to be significantly associated with the reporting of fatigue (Table 5.9). Though considerably more fatigue crashes occurred on straight sections of road, police were more likely to determine that the crash was fatigue-related when it occurred on a curved (14.3%) compared with a straight (9%) section of road. Overall, crashes on curved sections of road were 68% (OR=1.68 95%CI 1.49-1.89) more likely to be judged as fatigue-related compared with those occurring on straight sections of road.

Table 5.9 Frequency and odds of fatigue for police attended motor vehicle crashes; by road alignment, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		**No**		**Total**				
Road Alignment	n	%	n	%	n	%	**OR**	**95%CI**	**p**
Straight	1,191	9.0	12,029	91.0	13,220	100	1.00	-	-
Curved	422	14.3	2,531	85.7	32,953	100	1.68	1.49-1.89	.000
All	**1,613**	**10.0**	**14,560**	**90.0**	**16,173**	**100**			

N=568 crashes missing Road Alignment values ^Reference group for calculation of OR. Model X^2 68.91, df=1, p=0.000

5.1.5 Road Gradient

The distribution of fatigue-related crashes across the various road gradient types is presented in Table 5.10. Crashes on the crest of a hill accounted for approximately 2% of crashes attended by police and where fatigue was assessed. Approximately 6% of crashes occurring on this gradient type were reported to involve fatigue compared with 9.9% on level roads and 10.2% on sloping roads. When compared with crashes occurring on the crest of a hill, crashes on level (OR=1.70 95%CI 1.07-2.68) and sloping (OR=1.76 95%CI 1.10-2.82) sections of road were around 70% more likely to be fatigued-related.

Table 5.10 Frequency and odds of fatigue for police attended motor vehicle crashes; by road alignment, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		**No**		**Total**				
Road Gradient	n	%	n	%	n	%	**OR**	**95%CI**	**p**
Crest of Hill^	20	6.1	308	93.9	328	100	1.00	-	-
Level	1,263	9.8	11,565	90.2	12,828	100	1.68	1.06-2.65	.025
Slope	301	10.2	2,654	89.8	2,955	100	1.74	1.09-2.78	.019
All	**1,584**	**9.8**	**14,527**	**90.2**	**16,111**	**100**			

N=630 crashes with missing Road Gradient value. ^Reference group for calculation of OR. Model X^2 6.30, df=1, p=0.043

5.1.6 Road Surface

The surface of the road was found to be significantly associated with the determination of a police reported fatigue-related crash. In this instance, crashes that occurred on unsealed roads were around 40% less likely than those occurring on sealed roads to be fatigue-related: 6% *versus* 9.9% (OR=0.57 95%I 0.38-0.87).

Table 5.11 Frequency and odds of fatigue for police attended motor vehicle crashes; by road alignment, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		No		Total				
Road Surface	n	%	n	%	n	%	**OR**	**95%CI**	**p**
Sealed^	1,616	9.9	14,669	90.0	16,285	100	1.00	-	-
Unsealed	24	6.0	376	94.0	400	100	0.57	0.38-0.87	.010
All	**1,693**	**9.8**	**15,045**	**90.2**	**16,685**	**100**			

N=56 crashes with missing Road Surface value. ^Reference group for calculation of OR. Model X^2, 7.74 df=1, p=0.005

5.1.7 Speed Limit at Location of Crash

Increases in the posted speed limit at the location of the crash were associated with an increasing proportion of police reported fatigue-related crashes, with crashes in 80-90km/hour (12.8%) and 100+km/hour zones (23.5%) associated with an approximate 2.6 (OR=2.61 95%CI 2.13-3.31) and 5.5 (OR=5.50 95%CI 4.68-6.48) fold increase in the odds of the crash being fatigue-related compared with those occurring in a <50km/hour zone (Table 5.12). When the crashes were categorised by just two speed zones, those occurring in zones ≥80+km/hour (19.8%) were approximately four times (OR=4.13 95%CI 3.68-4.64) more likely to be fatigue-related compared with those occurring on roads <80km/hour.

Table 5.12 Frequency and odds of fatigue for police attended motor vehicle crashes; by speed zone of crash, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		**No**		**Total**				
Speed Zone	n	%	n	%	n	%	**OR**	**95%CI**	**p**
<50km/hour^	214	5.3	3,829	94.7	4,043	100	1.00	-	-
60-70km/hour	323	5.9	5,183	94.1	5,506	100	1.11	0.93-1.33	.230
Sub-total <80km/hour^	*537*	*5.6*	*9,012*	*94.4*	*9,549*	*100*	*1.00*	-	-
80-90km/hour	192	12.8	1,313	87.2	1,505	100	2.61	2.13-3.31	.000
≥100km/hour	661	23.5	2,147	76.5	2,808	100	5.50	4.68-6.48	.000
Sub-total ≥80km/hour	*853*	*19.8*	*3,460*	*80.2*	*4,313*	*100*	*4.13*	*3.68-4.64*	*.000*
All	**1,390**	**10.0**	**12,472**	**90.0**	**13,862**	**100**			

N=2,879 crashes with missing Speed Limit values. ^Reference group for calculation of OR. Model 4-speed levels X^2 682.52, df=3, p=.000. Model 2-speed levels X^2 605.16, df=1, p=.000

5.1.8 Time of Day

Two time periods were significantly associated with the occurrence of police reported fatigue-related crashes. Crashes occurring midnight to 6.00am (25.3%) and 4.01pm to 5.59pm (4.5%) evidenced the highest and lowest proportions of fatigue-related crashes respectively. Compared with crashes occurring 6.00pm to 11.59pm, crashes from midnight to 6.00am were nearly 3.7 times (OR=3.69 95%CI 3.18-4.28) *more* likely to be fatigue-related, while those occurring 4.01pm-5.59pm were 49% *less* likely to be fatigue-related.

Table 5.13 Frequency and odds of fatigue for police attended motor vehicle crashes; by time of day of crash, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		**No**		**Total**				
Time of Day	n	%	n	%	n	%	**OR**	**95%CI**	**p**
18:00-23:59^	370	8.4	4,033	91.6	4,403	100	1.00	-	-
00:00-06:00	494	25.3	1,458	74.7	1,952	100	3.69	3.18-4.28	.000
06:01-12:00	358	8.5	3,867	91.5	4,225	100	1.00	0.86-1.17	.907
12:01-13:59	123	8.0	1,408	92.0	1,531	100	0.95	0.77-1.17	.652
14:00-16:00	178	8.1	2,014	91.9	2,192	100	0.96	0.79-1.16	.695
16:01-17:59	103	4.5	2,171	95.5	2,274	100	0.51	0.41-0.64	.000
Total	**1,626**	**9.8**	**14,951**	**90.2**	**16,577**	**100**			

N=164 crashes with missing Crash Time values. ^Reference group for calculation of OR. Model X^2 506.860, df=5, p=.000

The time of day of crash was examined further in relation to single vehicle crashes only. Compared with the findings presented in Table 5.13, the proportion of fatigue-related single vehicle crashes was substantially higher at all specified times of day, with crashes midnight to 6.00am evidencing the highest proportion (30.1%). Compared with single vehicle crashes occurring 6.00pm to 11.59pm, the odds of a fatigue-related crashes occurring midnight to 6.00am were 3.2 times (OR=3.24 95%CI 2.73-3.84) higher. Significantly higher odds (31% to 46%) were also noted for other times of the day except for the time period 4.01pm to 5.59pm where single vehicle crashes were 28% *less* likely (OR=0.72 95%CI 0.54-0.96) to be fatigue-related.

Table 5.14 Frequency and odds of fatigue for police attended single vehicle crashes; by time of day of crash, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		**No**		**Total**				
Time of Day	n	%	n	%	n	%	**OR**	**95%CI**	**p**
18:00-23:59^	266	11.7	2,005	88.3	2,271	100	1.00	-	-
00:00-06:00	430	30.1	1,000	69.9	1,430	100	3.24	2.73-3.84	.000
06:01-12:00	221	15.4	1,212	84.6	1,433	100	1.37	1.13-1.66	.001
12:01-13:59	80	16.3	412	83.7	492	100	1.46	1.11-1.92	.006
14:00-16:00	120	14.8	689	85.2	809	100	1.31	1.04-1.65	.022
16:01-17:59	66	8.8	687	91.2	753	100	0.72	0.54-0.96	.025
Total	**1,183**	**16.5**	**6,005**	**83.5**	**7,188**	**100**			

N=85 single vehicle crashes with missing Crash Time values. ^Reference group for calculation of OR. Model X^2 506.860, df=5, p=.000

5.1.9 Day of Week

Crashes occurring on Saturdays (11.5%) and Sundays (15.3%) were most likely to be judged by police to be fatigue-related compared with other days of the week. Relative to crashes occurring on Monday, crashes on Saturday and Sunday were 26% (OR=1.26, 95%CI 1.04-1.53) and 75% (OR=1.75, 95%CI 1.45-2.11) respectively more likely to be judged as fatigue-related. In contrast, crashes occurring on a Friday (7.7%) (OR=0.81, 95%CI 0.66-0.9) were significantly less likely to be fatigue-related.

Table 5.15 Frequency and odds of fatigue for police attended motor vehicle crashes; by day of week of crash, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		No		Total				
Day of Week	n	%	n	%	n	%	**OR**	**95%CI**	**p**
Monday^	191	9.3	1,862	90.7	2,053	100	1.00	-	-
Tuesday	180	8.3	1,976	91.7	2,156	100	0.88	0.71-1.09	.275
Wednesday	182	7.8	2,161	92.2	2,343	100	0.82	0.64-1.01	.069
Thursday	232	9.3	2,270	90.7	2,502	100	0.99	0.81-1.21	.972
Friday	218	7.7	2,611	92.3	2,829	100	0.81	0.66-0.99	.047
Saturday	305	11.5	2,350	88.5	2,655	100	1.26	1.04-1.53	.016
Sunday	336	15.3	1,867	84.7	2,203	100	1.75	1.45-2.11	.000
All	**1,644**	**9.8**	**15,097**	**90.2**	**16,471**	**100**			

^Reference group for calculation of OR. Model X^2 106.08, df=6, p=.000

5.1.10 Vehicle Type

Because fatigue is reported in the IRIS crash database as a crash level and not a driver level factor, the description and estimate of the odds of fatigue among crashing drivers of a particular vehicle type is most reliably reported for single vehicle crashes only. For this report however, frequency counts have also been provided of all vehicle types involved in a multiple vehicle crash to fully describe their involvement in crashes judged to involve fatigue or otherwise.

Single Vehicle Crashes

Approximately 92% of *single vehicle* crashes judged to be fatigue-related involved a motorcar, followed by heavy vehicles (4%), and trucks (1.9%). Fatigue was proportionally higher among drivers of motorcars (17.7%) followed by drivers of heavy vehicles (16.5%) and trucks (14.1%). When compared with crashes involving drivers of motorcars, only single vehicle crashes involving riders of motorcycles were found to have significantly lower odds (83%) of being assessed as fatigued (OR=0.13 95%CI 0.13-0.23). Drivers of trucks and heavy vehicles involved in single vehicle crashes were not significantly more likely than drivers of crashing motor cars to be judged by police to be fatigued.

Table 5.16 Frequency and odds of fatigue for drivers involved in a police attended single vehicle crashes; by vehicle type, Western Australia 2009-2013

	Driver Level Fatigue								
	Yes		**No**		**Total**				
Vehicle Type	n	%	n	%	n	%	**OR**	**95%CI**	**p**
Motorcar^	1,114	17.7	5,182	82.3	6,296	100	1.00	-	-
Motorcycle	14	2.9	472	97.1	486	100	0.13	0.08-0.23	.000
Bus	1	3.2	30	96.8	31	100	0.15	0.02-1.13	.067
Truck	23	14.1	140	85.9	163	100	0.76	0.48-1.19	.237
Heavy Vehicle	49	16.5	248	83.5	297	100	0.91	0.67-1.25	.597
All	**1,201**	**16.5**	**6,072**	**83.5**	**7,273**	**100**			

^Reference group for calculation of OR. Model X^2 106.44, df=4, p=.000

Multiple Vehicle Crashes

Approximately 19,117 motorised vehicles were involved in the 9,468 multiple vehicle crashes assessed for fatigue (Table 5.17). As per the finding for single vehicle crashes, motorcars (91%) were the predominant vehicle type involved in a multiple vehicle crash judge to be fatigue-related, followed by trucks (2.9%) and heavy vehicles (3.6%). These proportions were only slightly higher than that observed for non-fatigue related multiple vehicle crashes.

Table 5.17 Frequency of motorised vehicle types involved in a police attended multiple motor vehicle crash; by fatigue status, Western Australia 2009-2013

	Crash Level Fatigue					
Vehicle Type	**Yes**		**No**		**Total**	
	n	%	n	%	n	%
Motorcar	817	91.2	16,467	90.4	17,284	100
Motorcycle	17	1.9	860	4.7	877	100
Bus	4	0.4	159	0.9	163	100
Truck	32	3.6	480	2.6	512	100
Heavy Vehicle	26	2.9	255	1.4	281	100
All	**896**	**100**	**18,622**	**100**	**19,117^**	**100**

^Total number of vehicles involved in multiple vehicle crashes, both fatigue and non-fatigue related

5.2 Characteristics of Drivers Involved in Fatigue-Related Crashes

As previously noted, the recording of fatigue in the IRIS crash dataset is a crash level variable. This limits the precise identification of driver characteristics such as sex, age, blood alcohol level, and licensing status to those involved in single vehicle crashes.

5.2.1 Sex

A statistically significant relationship was observed between fatigue and the sex of the driver involved in a single vehicle crash (Table 5.18). Males accounted for approximately 77% of drivers judged to be fatigued, with a higher proportion of crash involved males than females judged to be fatigued: 17% *versus* 14.5%. Overall, male drivers involved in a single vehicle crash were 23% more likely than females to be judged by attending police to be fatigued (OR=1.23 95%CI 1.06-1.43).

Table 5.18 Frequency and odds of fatigue for police attended single vehicle crashes; by driver sex, Western Australia 2009-2013

	Driver Level Fatigue								
	Yes		No		Total				
Driver Sex	n	%	n	%	n	%	**OR**	**95%CI**	**p**
Female^	274	14.5	1,661	85.5	1,944	100	1.00	-	-
Male	904	17.3	4,316	82.6	5,386	100	1.23	1.06-1.43	.005
All	**1,178**	**16.6**	**5,932**	**83.4**	**7,110**	**100**			

N=163 crash records with missing Sex value. ^Reference group for calculation of OR. Model X^2 8.17, df=1, p=0.004

5.2.2 Age

Around one in five drivers (20.5%) aged 20-24 years involved in a single vehicle crash were judged by police to be fatigued, with those aged 15-19 (11.4%) and 50-59 (15.1%) less likely to be judged as fatigued. Compared with the youngest age group, all older age drivers had significantly increased odds of being fatigued. As shown in Table 5.19, the odds of the involvement of fatigue was highest – two-fold increase- for those aged 20-24 (OR=2.0 95%CI 1.60-2.49) down to 37% for those aged 50-59 years (OR=1.37 95%CI 1.03-1.84).

Table 5.19 Frequency and odds of fatigue for police attended single vehicle crashes; by driver age, Western Australia 2009-2013

	Driver Level Fatigue								
	Yes		No		Total				
Driver Age	n	%	n	%	n	%	**OR**	**95%CI**	**p**
15-19^	131	11.4	1,015	88.6	1,146	100	1.00	-	-
20-24	295	20.5	1,143	79.5	1,438	100	2.00	1.60-2.49	.000
25-29	172	18.1	777	81.9	949	100	1.71	1.34-2.19	.000
30-39	226	17.4	1,074	82.6	1,300	100	1.63	1.29-2.05	.000
40-49	159	16.2	820	83.8	979	100	1.50	1.17-1.92	.001
50-59	88	15.1	495	84.9	583	100	1.37	1.03-1.84	.031
60-69	56	17.1	271	82.9	327	100	1.60	1.13-2.25	.007
70+^	37	17.7	172	82.3	209	100	1.66	1.11-2.48	.012
All	**1,164**	**16.8**	**5,767**	**83.2**	**6,931**	**100**			

N=342 crash records excluded (e.g., drivers < 15 years of age; missing Age value). ^Reference group for calculation of OR. Model X^2 42.60, df=7, p=.000

5.2.3 Alcohol

Analysis of the association between the single vehicle crash driver's fatigue status and their Blood Alcohol Concentration level (Table 5.20) showed that 27.5% (n=279) of drivers judged to be fatigued recorded a BAC greater than zero, with 227 recording ≥0.0500gm%. Within the various BAC level categories, drivers who recorded a BAC greater than zero but less than 0.0500gm% were most likely to be judged as fatigued (23%) compared with drivers returning a zero (16.5%) or ≥0.0500gm% BAC level (17%). Compared with crashing drivers with a zero BAC, drivers recording a BAC in the range 0.0001-0.0499gm% were 53% (OR=1.53 95%CI 1.11-2.12) more likely to be judged as fatigued by attending police.

Table 5.20 Frequency and odds of fatigue for police attended single vehicle crashes; by driver Blood Alcohol Concentration level, Western Australia 2009-2013

	Driver Level Fatigue								
	Yes		No		Total				
BAC Level (gm%)	n	%	n	%	n	%	**OR**	**95%CI**	**p**
0.0000^	736	16.5	3,776	83.7	4,512	100	1.00	-	-
0.0001-0.0499	52	23.0	174	77.0	226	100	1.53	1.11-2.12	.009
≥0.0500	227	17.0	1,107	83.0	1,334	100	1.05	0.89-1.23	.542
All	**1,015**	**16.7**	**5,057**	**83.3**	**6,072**	**100**			

N=1,201 single vehicle crash records with missing alcohol values. ^Reference group for calculation of OR. Model X^2 6.50, df=2, p=.039

5.2.4 Driver Licensing Status

Around nine in ten drivers (n=997) involved in a single vehicle, police attended crash involving fatigue were validly licensed at the time of the crash. However, the proportion of crashing drivers in each licence group who were judged to be fatigued was similar: 16.5% *versus* 18.4% (Table 5.21). Drivers without a valid licence were not significantly more likely than validly licensed drivers to be judged as fatigued (OR=1.14 95%CI 0.91-1.42).

Table 5.21 Frequency and odds of fatigue for police attended single vehicle crashes; by driver licensing status, Western Australia 2009-2013

	Driver Level Fatigue								
	Yes		No		Total				
Licence Status	n	%	n	%	n	%	**OR**	**95%CI**	**p**
Valid Licence^	997	16.5	5,040	83.5	6,037	100	1.00	-	-
No Valid Licence	102	18.4	452	81.6	554	100	1.14	0.91-1.42	.252
All	**1,099**	**16.7**	**5,492**	**83.3**	**6,591**	**100**			

N=682 single vehicle crash records with missing driver licence status value. ^Reference group for calculation of OR. Model X^2 1.028, df=1, p=0.257

6. APPLICATION OF THE AUSTRALIAN TRANSPORT SAFETY BUREAU OPERATIONAL DEFINITION OF FATIGUE TO REPORTED CRASHES IN WESTERN AUSTRALIAN 2009-20013

The step-wise methodology described by the ATSB (Dobbie, 2002) to identify fatigue-related crashes was applied to the dataset of 186,585 Western Australian crashes of all outcome severities (See Table 5.1). In the first instance, crashes with the following characteristics were ***excluded*** from consideration as fatigue-related crashes:

- *Crashes occurring on roads with speed limits under 80km/hour*;
- Crashes involving *collision with a pedestrian*, or
- Crashes involving an *unlicensed (i.e, with no authority to drive) or drink-driver (i.e., Blood Alcohol Concentration ≥0.05gm%)*.

Crash records with missing speed limit information were also excluded. However, records with missing driver licensing or alcohol information were retained. Missing information for these factors was assumed to imply that drivers were not likely in breach of alcohol or licensing regulations which would otherwise have been recorded.

Of the remaining records, only those crashes that met the following criteria were consequently identified as fatigue-related crashes under the operational definition:

- *Single vehicle crashes occurring between midnight and 6.00am and 2.00pm-4.00pm*, and,
- *Head-on crashes where neither vehicle was overtaking at the time*.

In the sections below, the fatigue-related crashes identified from the application of the ATSB operational definition are described, along with other findings of analyses addressing the correspondence and differences between ATSB defined and WA Police reported fatigue-related crashes.

A total of 2,498 crashes were identified from the application of the ATSB definition to be fatigue-related, representing approximately 1.3% of *all reported crashes* in Western Australia for the period. This is slightly higher than the 0.90% (n=1,644) identified from assessments made by WA Police of fatigue involvement. In absolute numbers, the application of the ATSB operational definition identified an additional 854 fatigue-related crashes over that identified by WA Police. It must be noted however, that this number is based on the analysis of the population of *all reported* crashes for the period (n=186,585) that met the motorised vehicle inclusion criteria and not just the subset of crashes that were attended by police and assessed for the involvement of fatigue (n=16,741).

Table 6.1 shows the distribution of ATSB identified fatigue-related crashes for each year of the period. Linear regression of the annual proportion of all reported crashes identified to be fatigued showed no significant variation over time (β= -.050; t= -1.66, p=0.194). This finding is consistent with that for the annual proportion of police attended and reported fatigue-related crashes.

Table 6.1 Annual frequency distribution of ATSB identified fatigue-related motor vehicle crashes, Western Australia 2009-2013

	Fatigue		**No Fatigue**		**Total**	
Year	**n**	**%**	**n**	**%**	**n**	**%**
2009	554	1.5	35,814	98.5	36,369	100
2010	492	1.3	38,093	98.7	38,585	100
2011	522	1.3	38,453	98.7	38,975	100
2012	526	1.4	38,083	98.6	38,609	100
2013	404	1.2	33,644	98.8	34,048	100
Total	**2,498**	**1.3**	**184,087**	**98.7**	**186,585**	**100**

The incidence rate *per 100,000 licensed drivers* and *registered vehicles* was calculated to be 157.50 (95%CI 151.32-163.67) and 130.60 (95%CI 125-135.72) respectively. Linear regression of the annual rates (Figure 6.1) showed no statistically significant variation in the incidence of ATSB defined fatigue-related crashes over time.

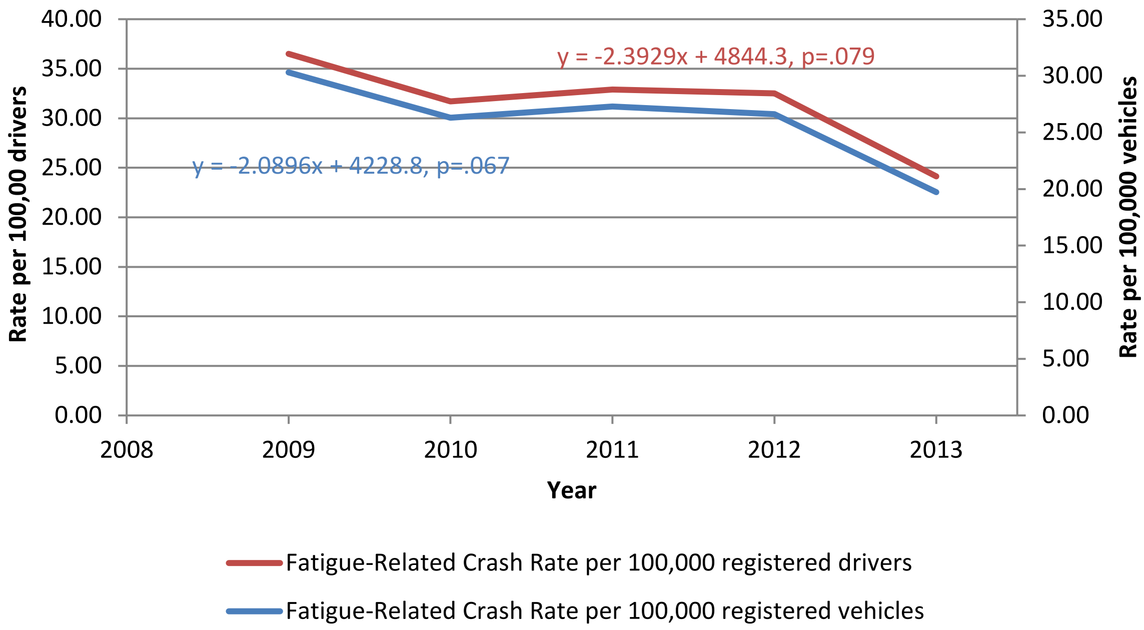

Figure 6.1 Annual rate of ATSB identified fatigue-related crashes per 100,000 registered drivers and per 100,000 registered vehicles; Western Australia 2009-2013

6.1 Crash, Environment and Temporal Characteristics of Fatigue-Related Crashes

6.1.1 Injury Severity

Table 6.2 shows the injury severity of crashes identified by the ATSB definition as fatigue-related. Approximately 76.7% (n=1,999) of identified crashes involved only minor injury or property damage only, which is comparable to the 71% calculated for police reported fatigue-related crashes. The number of identified fatigue-related fatal (n=104) and hospitalisation (n=479) crashes represented 12.6% and 4.9% of *all reported fatal and all reported hospitalisation* crashes respectively for the period. Compared with crashes that resulted in medical treatment or property damage only, the ATSB definition was approximately 13 times (OR=13.1 95%CI 10.6-16.2) and 4.6 times (OR=4.6 95%CI 4.2-5.1) more likely to identify a crash as fatigue-related when it resulted in death or hospitalisation respectively. These odds are five times that of police reported fatigue-related fatal crashes (OR=2.4) and three times that of police reported fatigue-related hospitalisation crashes (OR=1.5).

Table 6.2 Frequency and odds of ATSB identified fatigue-related motor vehicle crashes; by injury severity, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		**No**		**Total**				
Crash Severity	n	%	n	%	n	%	**OR**	**95%CI**	**p**
MT/PDO^	1,915	1.1	174,062	98.9	175,977	100	1.00	-	-
Hospitalisation	479	4.9	9,305	95.1	9,784	100	4.67	4.2-5.1	.000
Fatality	104	12.7	718	87.3	822	100	13.16	10.6-16.2	.000
All	**2,498**	**1.1**	**184,085**	**98.7**	**186,583**	**100**			

MT-PDO: Medical Treatment or Property Damage Only. ^Reference group for calculation of OR. Model X^2 940.45, df=2, p=0.000

Further examination of the relationship between injury severity (categorised by KSI outcomes) and identified fatigue by the regional location of the crash is presented in Table 6.3. Around 5.6% of KSI crashes across Western Australia were identified to be fatigue-related by the ATSB definition compared with 13.3% from police reports. The proportion was substantially higher for KSI crashes occurring in Regional WA (12.3%) but lower for Metropolitan Perth (2.1%), both of which are lower than that determined from police reports: 19.6% and 8.5% respectively. For all of Western Australia, KSI crashes were five times (OR=5.28 95%CI 4.80-5.81) more likely than non-KSI crashes to be identified as fatigue-related by the ASTB definition (compared with 1.6 times based on police reports). Similarly the odds of fatigue were significantly higher for KSI crashes occurring in Metropolitan Perth (OR=4.57 95%CI 3.83-5.45) and Regional WA (OR=2.91 95%CI 2.59-3.27).

Table 6.3 Frequency and odds of ATSB identified fatigue-related motor vehicle crashes; by region and injury severity, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		**No**		**Total**				
Region/Severity	n	%	n	%	n	%	**OR**	**95%CI**	**p**
Metro Perth									
Non-KSI^	716	0.5	149,197	99.5	149,913	100	1.0	-	-
KSI	153	2.1	6,968	97.9	7,121	100	4.57	3.83-5.45	.000
All	**869**	**0.6**	**156,165**	**99.4**	**157,034**	**100**			
Regional WA									
Non-KSI^	1,199	4.6	24,862	95.4	26,061	100	1.0	-	-
KSI	430	12.3	3,055	87.7	3,485	100	2.91	2.59-3.27	.000
All	**1,629**	**5.5**	**27,917**	**94.5**	**29,546**	**100**			
All of WA									
Non-KSI^	1,915	1.1	174,062	98.9	175,977	100	1.0	-	-
KSI	583	5.5	10,023	94.5	10,606	100	5.28	4.80-5.81	.000
All	**2,498**	**1.3**	**248,229**	**98.7**	**186,583**	**100**			

N=3 crashes missing region value ^Reference group for calculation of OR. KSI: Killed or Seriously Injured. *Metro Perth Model* X^2 206.14, df=1, p=.000; *Regional WA Model* X^2 278.70, df=1, p=.000; *All of WA Model* X^2 873.06, df=1, p=.000

6.1.2 Region

Approximately 65% (n=1,629) of crashes identified to involve fatigue from the application of the ATSB operational definitional occurred in Regional WA. As shown in Table 6.4, a higher proportion of crashes occurring in Regional WA were identified to be fatigue-related (5.5%) compared with Metropolitan Perth (0.6%). Crashes occurring in Regional WA were around 10 times (OR=10.4 95%CI 9.6-11.3) more likely than those occurring in Metropolitan Perth to be categorised as fatigue-related. This is 5.6 times the odds calculated for Regional WA fatigue crashes reported by police.

Table 6.4 Frequency and odds of ATSB identified fatigue-related motor vehicle crashes; by region of crash, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		No		Total				
Crash Region	n	%	n	%	n	%	**OR**	**95%CI**	**p**
Metro Perth^	869	0.6	156,167	99.4	157,036	100	1.00	-	-
Regional WA	1,629	5.5	27,917	94.5	27,917	100	10.4	9.6-11.3	.000
All	**2,498**	**1.3**	**184,084**	**98.7**	**186,582**	**100**			

n=3 missing crash Region value. ^Reference group for calculation of OR Model: X^2 3138.56, df=1, p=.000

Disaggregating the Regional WA crashes by MRWA region showed substantial variation in the incidence of ATSB identified fatigue-related crashes (Table 6.5). The incidence of identified fatigue was lowest in the South-West (3.6%) and Goldfields-Esperance (4%) regions and highest in the Wheatbelt (11.2%) region. Crashes in this region accounted for 18% of all identified fatigue-related crashes and yet represented just 2.1% of all reported crashes and1.9% of crashes not identified to be fatigue-related.

Table 6.5 Frequency and odds of ATSB identified fatigue-related motor vehicle crashes; by Main Roads WA region, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		No		Total				
MRWA Region	n	%	n	%	n	%	**OR**	**95%CI**	**p**
Metro Perth^	869	0.6	156,167	99.4	157,036	100	-	-	-
Goldfields-Esperance	108	4.0	2,593	96.0	2,701	100	7.4	6.1-9.1	.000
Great Southern	153	5.6	2,584	94.4	2,737	100	10.6	8.9-12.6	.000
Kimberley	69	5.7	1,149	94.3	1,218	100	10.7	8.3-13.8	.000
Mid West Gascoyne	224	7.0	2,966	93.0	3,190	100	13.5	11.6-15.7	.000
Pilbara	127	5.7	2,098	94.3	2,225	100	10.8	8.9-13.1	.000
South-West	480	3.6	13,022	96.4	13,502	100	6.6	5.9-7.4	.000
Wheatbelt	468	11.8	3,505	88.2	3,973	100	23.9	21.3-26.9	.000
All	**2,498**	**1.3**	**184,084**	**100**	**186,582**	**100**			

n=3 crashes with missing MRWA Region value. ^Reference group for calculation of OR. Model X^2 3507.37, df=7, p=.000

Compared with crashes occurring in Metropolitan Perth, all regional areas evidenced significantly higher odds of a crash being defined as fatigue-related, particularly in the Wheatbelt region where crashes were 24 times (OR=23.9 95%CI 21.3-26.9) more likely than in Metropolitan Perth to be identified as fatigue-related through the application of the ATSB operational definition.

6.1.3 Crash Type

The ATSB operational definition for fatigue specifies the inclusion of single-vehicle crashes (occurring at restricted times of the day) and head-on collisions (that do not involve overtaking) and no other types. Table 6.6 shows that just over eight in ten crashes identified by the ATSB operational definition to be fatigue-related were single vehicle crashes, which is similar to the seven in ten police identified fatigue-related crashes that were also single vehicle. The bias of the ATSB operational definition toward single vehicle crashes has resulted in an unsurprising finding of the identification of a higher proportion of fatigue (6.6%) among this crash type compared with just 0.3% for only one class of multiple vehicle crash (i.e., head-on without overtaking). Further examination of the single vehicle crash types showed that the majority (63%) involved a vehicle leaving the road and colliding with an object.

Table 6.6 Frequency of ATSB identified fatigue-related motor vehicle crashes; by crash type, Western Australia 2009-2013

	Crash Level Fatigue					
Crash Type	**Yes**		**No**		**Total**	
	n	%	n	%	n	%
Multiple Vehicle	541	0.3	156,572	99.7	157,113	100
Single Vehicle	1,957	6.6	27,515	93.4	29,472	100
All	2,498	1.3	184,087	98.7	186,585	100

6.1.4 Road Alignment

Though considerably more fatigue-related crashes occurred on straight sections of road, a significantly higher proportion of crashes on curves (2.1%) compared with crashes on straight sections of road (1.1%) were identified by the ATSB definition to be fatigue-related. Overall, crashes on curved sections of road were around 2.4 times (OR=2.36 95%CI 2.17-2.57) more likely to be identified as fatigue-related compared with those occurring on straight sections of road. This finding is commensurate with that observed for police reported fatigue-related crashes.

Table 6.7 Frequency and odds of ATSB identified fatigue-related motor vehicle crashes; by road alignment, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		**No**		**Total**				
Road Alignment	n	%	n	%	n	%	**OR**	**95%CI**	**p**
Straight	1,570	1.1	139,810	98.9	141,380	100	1.00	-	-
Curved	852	2.6	32,123	97.4	32,975	100	2.36	2.17-2.57	.000
All	**2,422**	**1.1**	**171,933**	**98.6**	**174,355**	**100**			

N=12,230 crashes missing Road Alignment values ^Reference group for calculation of OR. Model X^2 360.40, df=1, p=0.000

6.1.5 Road Gradient

Crashes on the crest of a hill accounted for the least number of crashes identified from the ATSB definition to be fatigue-related but proportionally were more likely to be identified as fatigue-related (2.1%) compared with crashes occurring on level road (1.3%) or sloping roads (1.8%). Crashes on the latter two roads were consequently 49% (OR=0.51 95%CI 0.40-0.69) and 27% (OR=0.73 95%CI 0.57-0.94) respectively less likely to be identified as fatigue-related by the ATSB definition. This finding is contrary to the increased odds of fatigue involvement observed for crashes on level (OR=1.68) and sloping (OR=1.74) roads from police reports.

Table 6.8 Frequency and odds of ATSB identified fatigue-related motor vehicle crashes; by road gradient, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		**No**		**Total**				
Road Gradient	n	%	n	%	n	%	**OR**	**95%CI**	**p**
Crest of Hill^	76	2.4	3,068	97.6	3,144	100	1.00	-	-
Level	1,797	1.3	141,084	98,7	142,881	100	0.51	0.40-0.69	.000
Slope	512	1.8	27,986	98.2	28,498	100	0.73	0.57-0.94	.015
All	**2,385**	**1.1**	**172,138**	**98.6**	**174,523**	**100**			

N=12,062 crashes with missing Road Gradient value. ^Reference group for calculation of OR. Model X^2 98.89, df=1, p=0.037

6.1.6 Road Surface

While most crashes identified by the ATSB to be fatigue-related occurred on sealed roads, a greater proportion of crashes on unsealed road were identified by the ATSB definition to be fatigue-related (7.3% *versus* 1.2%). Consequently, crashes on unsealed roads were around six times (OR=6.30 95%CI 5.50-7.22) more likely to be identified as fatigue-related compared with those occurring on sealed roads. This finding is contrary to that identified from police reports where crashes on unsealed roads were 43% *less* likely to be fatigue-related.

Table 6.9 Frequency and odds of ATSB identified fatigue-related motor vehicle crashes; by road surface, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		**No**		**Total**				
Road Surface	n	%	n	%	n	%	**OR**	**95%CI**	**p**
Sealed^	2,216	1.2	178,606	98.9	180,822	100	1.00	-	-
Unsealed	250	7.3	3,195	92.7	3,445	100	6.30	5.50-7.22	.000
All	**2,466**	**1.3**	**181,801**	**98.7**	**184,267**	**100**			

N=2,318 crashes with missing Road Surface value. ^Reference group for calculation of OR. Model X^2, 467.89 df=1, p=0.000

6.1.7 Speed Limit

The restriction of ATSB identified fatigue-related crashes to those occurring on roads ≥80km/hour has necessarily restricted the analysis of the relationship between speed limit and fatigue to two categories: *80-90km/hour* and *≥100km/hour*. This restriction and missing values for speed means that approximately 86% of all reported crashes were excluded from the following analysis.

Approximately nine in ten crashes occurring on roads with a posted speed limit ≥80km/hour were not identified from the ATSB definition to involve fatigue, presumably because these crashes did not meet the additional crash type criteria (i.e., single vehicle at certain times of the day; head-on collision without overtaking). Similarly eight in ten crashes occurring in the ≥80km/hour speed zone assessed by police were judged not to involve fatigue.

Seven in ten crashes identified to be fatigue-related by the ATSB definition occurred on roads with a posted speed limit of ≥100km/hour, which is similar to that observed for police reported crashes (77%) for the subset of fatigue-related crashes occurring on ≥80km/hour roads. Crashes in this high speed zone were around 2.3 times (OR=2.3 95%CI 2.12-2.54) more likely to be identified as fatigue-related by the ATSB definition compared with crashes occurring on roads zoned 80-90km/hour.

Table 6.10 Frequency and odds of ATSB identified fatigue-related motor vehicle crashes; by speed zones ≥80km/hour, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		No		Total				
Speed Zone	n	%	n	%	n	%	**OR**	**95%CI**	**p**
80-90km/hour^	718	6.0	11,188	94.0	11,906	100	1.00	-	-
≥100km/hour	1,780	13.0	11,942	87.0	13,722	100	2.32	2.12-2.54	.000
All	**2,498**	**9.7**	**23,911**	**90.3**	**25,628**	**100**			

N=160,957 crashes with missing Speed Limit value or excluded because speed limit <80km/hour. ^Reference group for calculation of OR. Model X^2 , 361.98 df=1, p=0.000

6.1.8 Time of Day

The examination of the relationship between time of day of crash and fatigue was similarly biased by the ATSB operational definition restricting the selection of single vehicle crashes to 2.00pm-4.00pm and midnight to 6.00am. Consequently, separate analyses for time of day were undertaken for single vehicle and multiple vehicle crashes.

Single Vehicle Crashes

As previously reported (Table 6.6), around eight in ten crashes identified by the ATSB operational definition to be fatigued-related were single vehicle crashes. When cross-tabulated by the operational criteria times of day, 57.2% occurred between midnight and 6.00am and 42.8% between 2.00pm and 4.00pm. In contrast, 36% and 10% of single vehicle crashes reported by police to involve fatigue occurred midnight to 6.00am and 2.00pm-4.00pm respectively.

Multiple Vehicle Crashes

Only one type of multiple vehicle crash – head-on without overtaking – is defined by the ATSB operational definition to involve fatigue. This crash type was analysed by time of day in comparison with other multiple vehicle crash types. As shown in Table 6.11, nearly one-third of multiple vehicle crashes (head-on without overtaking) identified to involve fatigue occurred 2.00pm-4.00pm compared with 17.7% of non-fatigue multiple crashes of all types. Compared with crashes occurring 6.00pm to midnight, multiple vehicle crashes occurring midnight to 6.00am and 2.00pm to 4.00pm were three times (OR=3.06 955CI 2.17-4.33) and two-fold (OR=1.98 95%CI 1.52-2.59) more likely to be identified as fatigue-related. In contrast, multiple vehicle crashes occurring noon to 1.59pm and 4.01pm to 5.59pm were 39% less likely to be identified as fatigue-related under the operational definition(OR=0.61 95%CI 0.41-0.92; OR=0.61 95%CI 0.43-0.86).

Table 6.11 Frequency and odds of ATSB identified fatigue-related multiple vehicle crashes; by time of day of crash, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes*		**No****		**Total**				
Time of Day	n	%	n	%	n	%	**OR**	**95%CI**	**p**
18:00-23:59^	77	14.3	23,819	15.3	23,896	15.3	1.00	-	-
00:00-06:00	56	10.4	5,646	3.6	5,702	3.6	3.06	2.17-4.33	.000
06:01-12:00	138	25.7	53,600	34.4	53,738	34.4	0.79	0.60-1.05	.110
12:01-13:59	34	6.3	17,045	10.9	17,079	10.9	0.61	0.41-0.92	.019
14:00-16:00	177	32.9	27,542	17.7	27,719	17.7	1.98	1.52-2.59	.000
16:01-17:59	56	10.4	28.162	18.1	28,218	18.0	0.61	0.43-0.86	.006
Total	**538**	**100**	**155,814**	**100**	**156,352**	**100**			

N=761 multiple vehicle crashes with missing Crash Time values *Multiple vehicle head-on crashes without overtaking only. **All multiple vehicle crashes. ^Reference group for calculation of OR. Model X^2 147.22, df=5, p=.000

6.1.9 Day of Week

As was noted for police reported fatigue crashes, the incidence of ATSB identified fatigue-related crashes was highest on Saturdays (1.8%) and Sundays (2.5%) relative to other days of the week. Compared with crashes occurring on Monday, crashes occurring Tuesday to Friday were significantly *less likely* (ranging between 15% to 24% reduction) to be defined by the ATSB definition as fatigue-related. In comparison, crashes occurring Saturday and Sunday were respectively 37% (OR=1.37 95%CI 1.19-1.58) and 88% (OR=1.88 95%CI 1.63-2.17) *more likely* to be fatigue related.

Table 6.12 Frequency and odds of ATSB identified fatigue-related motor vehicle crashes; by day of week, Western Australia 2009-2013

	Crash Level Fatigue								
	Yes		No		Total				
Day of Week	n	%	n	%	n	%	**OR**	**95%CI**	**p**
Monday^	343	1.3	25,066	98.7	25,409	100	1.00	-	-
Tuesday	294	1.0	28,220	99.0	28,514	100	0.76	0.65-0.89	.001
Wednesday	302	1.0	28,911	99.0	29,213	100	0.76	0.65-0.89	.001
Thursday	313	1.0	29,621	99.0	29,934	100	0.77	0.62-0.90	.001
Friday	379	1.2	32,337	98.8	32,716	100	0.85	0.73-0.99	.039
Saturday	439	1.8	23,302	98.2	23,741	100	1.37	1.19-1.58	.000
Sunday	428	2.5	16,630	97.5	17,058	100	1.88	1.63-2.17	.000
All	**2,498**	**1.3**	**184,087**	**98.7**	**186,585**	**100**			

^Reference group for calculation of OR. Model X^2 256.704, df=6, p=.000

6.1.10 Vehicle Type

As per the analysis of police assessed crashes, separate analyses of the relationship between vehicle type and fatigue were undertaken for single and multiple vehicle crashes because of the crash level nature of the reporting of fatigue. For the latter crash type, vehicle types are presented as a proportion of the total number of vehicles involved in the multiple vehicle crash.

Single Vehicle Crashes

Approximately 87% of *single vehicle* crashes defined by the ATSB definition to be fatigue-related involved a motorcar, followed by heavy vehicles (5.3%), and trucks (2.8%). These proportions were similar to that observed for police reported fatigue-related crashes. However, for crashes involving each vehicle type the proportion of cars (6.6%), trucks (9.1%) and heavy vehicles (14.9%) defined by the ATSB to involve fatigue was lower than that observed for police reports (17.7%, 14.1% and 16.5% respectively). Whereas police assessed single vehicle crashes involving heavy vehicles and trucks were not more likely to be fatigue-related than those involving cars, the application of the ATSB definition showed that single vehicle crashes involving trucks and heavy vehicle were respectively 41% (OR=1.41 95%CI 1.06-1.87) and 2.5 times (OR=2.48 95%CI 2.00-3.07) *more likely* to be defined as fatigue-related. As was observed for police assessed crashes, single vehicle crashes involving motor cycles were significantly less likely (42% reduction) to be defined as fatigue-related.

Table 6.13 Frequency and odds of ATSB identified fatigue-related single vehicle crashes: by vehicle type, Western Australia 2009-2013

	Driver Level Fatigue								
	Yes		No		Total				
Vehicle Type	n	%	n	%	n	%	**OR**	**95%CI**	**p**
Motorcar^	1,711	6.6	24,181	93.4	25,892	100	1.00	-	-
Motorcycle	82	4.0	1,984	96.0	2.066	100	0.58	0.46-0.73	.000
Bus	5	2.3	209	97.7	214	100	0.33	0.13-0.82	.017
Truck	55	9.1	549	90.9	604	100	1.41	1.06-1.87	.015
Heavy Vehicle	104	14.9	592	85.1	696	100	2.48	2.00-3.07	.000
All	**1,957**	**6.4**	**27,515**	**93.4**	**29,472**	**100**			

^Reference group for calculation of OR. Model X^2 99.75, df=4, p=.000

Multiple Vehicle Crashes

The n=538 multiple vehicle crashes identified by the ATSB definition to involve fatigue involved 996 vehicles. While motorcars remained the predominant vehicle type to be involved in both fatigue (79.6%) and non-fatigue (93.9%) related multiple vehicle crashes, Table 6.14 also shows that 11.1% and 5.7% of vehicles involved in a fatigue-related multiple vehicle crash were heavy vehicles and trucks respectively, compared with 0.8% and 2.6% respectively of non-fatigue related multiple vehicle crashes. These proportions are considerably different to that observed for multiple vehicle police assessed crashes, where 6.5% and 4% of vehicles involved in fatigue and non-fatigue related crashes respectively were heavy vehicles and trucks.

Table 6.14 Frequency of motorised vehicle types involved in ATSB defined fatigue-related multiple vehicle crashes, Western Australia 2009-2013

	Crash Level Fatigue					
Vehicle Type	**Yes**		**No**		**Total**	
	n	%	n	%	n	%
Motorcar	793	79.6	279,984	93.9	280,777	100
Motorcycle	28	2.8	5,510	1.8	5,538	100
Bus	7	0.7	2,686	0.9	2,693	100
Truck	57	5.7	7,801	2.6	7,858	100
Heavy Vehicle	111	11.1	2,317	0.8	2,428	100
All	**996**	**100**	**298,298**	**100**	**299,294**^	**100**

^Total number of vehicles involved in multiple vehicle crashes, both fatigue and non-fatigue related

6.2 Characteristics of Drivers Involved in ATSB Defined Fatigue Related Crashes

Only two driver characteristics – sex and age – could be investigated for ATSB defined fatigue-related crashes and only in relation to single vehicle crashes because of the crash level nature of the application of the operational definition. Driver blood alcohol concentration and driver licensing status were not examined because these factors were automatically excluded under the operational definition for fatigue-related crashes.

6.2.1 Sex

Contrary to the finding of males being significantly more likely to be involved in a police reported fatigue-related single vehicle crash, males (6.8%) were not significantly more likely than females (6.8%) to be involved in ATSB defined fatigue-related single vehicle crashes (OR=1.0 95%CI 0.90-1.18).

Table 6.15 Frequency and odds of ATSB identified fatigue-related single vehicle crashes; by driver sex, Western Australia 2009-2013

	Driver Level Fatigue								
	Yes		**No**		**Total**				
Driver Sex	n	%	n	%	n	%	**OR**	**95%CI**	**p**
Female^	518	6.8	7,109	93.2	7,627	100	1.00	-	-
Male	1,384	6.8	18,864	93.2	20,248	100	1.00	0.90-1.18	.898
All	**1,902**	**6.8**	**25,973**	**93.2**	**27,875**	**100**			

N=1,597single vehicle crash records with missing Sex value. ^Reference group for calculation of OR. Model X^2 0.17, df=1, p=0.898

6.2.2 Age

There was minimal variation in the incidence of ATSB identified fatigue across the driver age groups, with the highest incidence reported for those aged 60-69 years (9%) and the lowest among those aged 15-19 years (5.7%). Compared with the latter group of drivers, those aged 25-29 (30% increase), 30-39 (38% increase), 40-49 (38% increase), 50-59 (27% increase) and 60-69 (64%) evidenced significantly higher odds of being fatigued as per the ATSB definition. These findings are reasonably consistent with those observed for police reported crashes, with the exception of those aged 70+ years.

Table 6.16 Frequency and odds of ATSB identified fatigue-related single vehicle crashes; by driver age, Western Australia 2009-2013

	Driver Level Fatigue								
	Yes		No		Total				
Driver Age	n	%	n	%	n	%	**OR**	**95%CI**	**p**
15-19^	236	5.7	3,909	94.3	4,145	100	1.00	-	-
20-24	350	6.6	4,989	93.4	5,339	100	1.16	0.98-1.37	.084
25-29	269	7.3	3,418	92.7	3,687	100	1.30	1.08-1.56	.004
30-39	400	7.7	4,793	92.3	5,193	100	1.38	1.17-1.63	.000
40-49	297	7.7	3,566	92.3	3,863	100	1.38	1.56-1.64	.000
50-59	176	7.1	2,287	92.9	2,463	100	1.27	1.04-1.56	.018
60-69	110	9.0	1,110	91.0	1,220	100	1.64	1.29-2.07	.000
70+^	49	6.9	662	93.1	711	100	1.22	0.89-1.68	.210
All	**1,887**	**7.1**	**24,734**	**92.9**	**26,621**	**100**			

N=2,851 single vehicle crash records excluded (e.g., drivers < 15 years of age) or missing Age value. ^Reference group for calculation of OR. Model X^2 27.05, df=7, p=.000

6.3 Correspondence of the ATSB identified and WAPOL reported fatigue-related crashes

The following restrictions were applied to the dataset of all reported crashes (n=186,585) for the analysis of the correspondence in fatigue reporting by WA Police and the application of the ATSB operational definition: (i) crashes not attended by police were *deleted* and (ii) crashes attended by police where no assessment of fatigue was reported were *deleted*.

The final dataset for the correspondence analysis consisted of 16,741 crashes with both a WAPOL report on the assessment of fatigue and a decision on the involvement of fatigue based on the application of the ATSB operational definition. Approximately 9.8% of these crashes were reported by police to involve fatigue compared with 4.8% based on the application of the ATSB operational definition. This translates to around 833 more fatigue-related crashes identified by police after discounting the n=265 crashes which were commonly judged by police and from the application of the ATSB definition to be fatigue-related.

Table 6.17 shows that 16.1% of crashes (n=265) identified by police to be fatigue related were similarly rated as fatigue-related from the application of the ATSB operational definition. These commonly identified crashes are defined by the ATSB operational criteria (e.g., single vehicle crashes at specified times of day and head-on without overtaking). A total of 1,379 crashes, or 83.9%, assessed by police to involve fatigue were not likewise rated from the application of the ATSB operational definition.

Table 6.17 Correspondence between ATSB and WAPOL for the identification of fatigue involvement in a police attended motor vehicle crash; Western Australia 2009-2013

WAPOL identification of fatigue involvement in a crash	**ATSB identification of fatigue involvement in a crash**					
	Fatigue		**No Fatigue**		**Total**	
	n	Row % *Col %*	n	Row % *Col %*	n	Row % *Col %*
Fatigue	265	16.1 *32.7*	1,379	83.9 *8.7*	1,644	100 *9.9*
No Fatigue	546	3.6 *67.3*	14,551	96.4 *91.3*	15,097	100 *91.9*
All Crashes	**811**	**4.8** ***100***	**15,930**	**95.2** ***100***	**16,741**	***100*** ***100***

X^2 502.73, df=1, p=.000

For crashes rated to involve fatigue from the application of the ATSB operation definition, 32.7% were similarly rated as fatigued by police with a further 546 crashes, or 67.3%, not rated by police to involve fatigue. In contrast, there was a much higher level of agreement between police and the ATSB operational definition for crashes that were judged *not to involve fatigue*, ranging between 91.3% and 96.4%.

Further investigation of the correspondence between the ATSB operational definition and the assessment by police was undertaken in relation to injury severity (Table 6.18-

6.20) and region of the crash (Table 6.21) to investigate the effect of these factors. Stratifying the data by injury severity showed somewhat increased levels of agreement between police and the ATSB operational definition for the identification of fatigue among crashes that resulted in a fatality or a hospitalisation but not minor injury or property damage only, compared with all injury outcomes. Nearly three in ten (27.3%) fatal crashes identified by police to be fatigue-related were similarly rated by the ATSB operational definition (Table 6.18). This proportion was reduced to around two in ten (20.5%) for fatigue-related crashes resulting in a hospitalisation (Table 6.19), which is slightly higher than the level for all injury outcomes (Table 6.17).

Table 6.18 Correspondence between ATSB and WAPOL for the identification of fatigue involvement in a police attended motor vehicle crash resulting in a fatality; Western Australia 2009-2013

WAPOL identification of fatigue involvement in a fatal crash/	**ATSB identification of fatigue involvement in a fatal crash**					
	Fatigue		**No Fatigue**		**Total**	
	n	Row % *Col %*	n	Row % *Col %*	n	Row % *Col %*
Fatigue	15	27.3 *39.5*	40	72.7 *16.1*	56	100 *19.2*
No Fatigue	23	10.4 *60.5*	208	90.0 *83.9*	231	100 *80.8*
Total Fatal Crashes	**38**	**13.3** ***100***	**248**	**86.7** ***100***	**286**	**100** ***100***

X^2 11.56, df=1, p=.001

Table 6.19 Correspondence between ATSB and WAPOL for the identification of fatigue involvement in a police attended motor vehicle crash resulting in a hospitalisation; Western Australia 2009-2013

WAPOL identification of fatigue involvement in a hospitalisation crash/	**ATSB identification of fatigue involvement in a hospitalisation crash**					
	Fatigue		**No Fatigue**		**Total**	
	n	Row % *Col %*	n	Row % *Col %*	n	Row % *Col %*
Fatigue	86	20.5	333	79.5	419	100
		37.4		*10.9*		*12.8*
No Fatigue	144	5.0	2,712	95.0	2,856	100
		62.6		*89.1*		*87.2*
Total Hospitalisation Crashes	**230**	**7.0**	**3,045**	**93.0**	**3,275**	**100**
		100		***100***		***100***

X^2 134.14, df=1, p=.000

Table 6.20 Correspondence between ATSB and WAPOL for the identification of fatigue involvement in a police attended motor vehicle crash resulting in MT/PDO; Western Australia 2009-2013

WAPOL identification of fatigue involvement in MT/PDO	**ATSB identification of fatigue involvement in a hospitalisation crash**					
	Fatigue		**No Fatigue**		**Total**	
	n	Row % *Col %*	n	Row % *Col %*	n	Row % *Col %*
Fatigue	164	14.0	1,006	86.0	1,170	100
		30.2		*8.0*		*8.9*
No Fatigue	379	3.2	11,631	96.8	12,010	100
		69.8		*92.0*		*91.1*
Total MT/PDO Crashes	**543**	**4.1**	**12,637**	**95.9**	**12,637**	**100**
		100		***100***		***100***

MT/PDO: Medical Treatment/Property Damage Only. X^2 318.39, df=1, p=.000

Stratifying the data by crash region (Table 6.21) showed that the application of the ATSB operational definition identified *fewer* police identified fatigue-related crashes in the metropolitan area (10.3%) compared with all areas (16.1%) but slightly more (22.3%) for crashes occurring in Regional WA.

Table 6.21 Correspondence between ATSB and WAPOL for the identification of fatigue involvement in a police attended motor vehicle crash in Metropolitan Perth and Regional WA; Western Australia 2009-2013

Region of Crash/WAPOL identification of fatigue involvement in a crash/	**ATSB identification of fatigue involvement in a crash**					
	Fatigue		**No Fatigue**		**Total**	
	n	Row % *Col %*	n	Row % *Col %*	n	Row % *Col %*
Metropolitan Perth						
Fatigue	87	10.3	757	89.7	844	100
		38.8		*7.2*		*7.8*
No Fatigue	137	1.4	9,827	98.6	9,964	100
		61.2		*92.8*		*92.2*
All Metropolitan Crashes	224	2.1	10,584	97.9	10,808	100
		100		*100*		*100*
Regional WA						
Fatigue	178	22.3	622	77.8	800	100
		30.3		*11.6*		*13.5*
No Fatigue	409	8.0	4,724	92.0	5,133	100
		69.7		*88.4*		*86.5*
All Regional WA Crashes	587	9.9	5,346	90.1	5,933	100
		100		*100*		*100*

Metropolitan crashes X^2 305.93, df=1, p=.000; Regional Crashes X^2 158.35, df=1, p=.000

The findings presented above suggest that the injury severity of the crash and the region of the crash have a marginal bearing on the correspondence between police reported and ATSB defined fatigue-related crashes.

Further analyses were undertaken of the 1,379 crashes judged by police to be fatigue-related crashes, but not defined as so from the ATSB definition, to examine how the ATSB definitional criteria have impacted on the observed correspondence. The findings of this examination are presented in Table 6.22. It should be noted that the examination did not consider all possible combinations of the definitional criteria that might lead to the exclusion of a particular crash as fatigue-related by the ATSB definition (e.g., an unlicensed driver with a BAC exceeding 0.050gm% involved a single vehicle crash early evening on a road with a posted speed limited below 80km/hour). Instead, the analysis was restricted to a broader level examination of the definitional criteria.

Table 6.22 Description of the reported crashes identified by WAPOL to be fatigue-related but not by the ATSB operational definition; Western Australia 2009-2013

Factor	N=1,379	%
Alcohol (BAC gm%)		
0.000	868	62.9
0.0001-0.0499	53	3.8
≥0.0500	284	20.6
Unknown	174	12.6
Licensing Status		
Validly Licenced	1,157	83.9
No Valid Licence	124	9.0
Unknown	98	7.1
Speed Limit (km/hour)		
< 80	537	38.9
≥ 80	588	42.6
Unknown	254	18.4
Crash Type and/or Time of Day of Crash		
Single Vehicle Crash	974	70.6
Outside critical event times	*633*	*65.0*
Within critical event times	*323*	*33.0*
Unknown time of day	*18*	*1.8*
Multiple Vehicle Crash	405	29.4
Other than head-on	*344*	*84.9*
Head-on	*45*	*11.1*
Unknown crash type	*16*	*4.0*

From Table 6.22 it is initially evident that nearly 46% (n=633) of police identified fatigue-related crashes would have been excluded from consideration by the ATSB operational definition as they were single vehicle crashes that occurred *outside the nominated critical time periods of 00:00-6.00am and 14:00-16:00*. Further to this, around one-quarter (n=344) of crashes would have been excluded because they were neither single vehicle nor head-on crashes. Alcohol was also a major factor, as around one in five crashes identified by police involved a driver with a BAC ≥ 0.0500gm%. Lastly, the speed limit at the location of the crash appears to be a critical factor as nearly four in ten police identified fatigue-related crashes would have been excluded because the crash occurred on roads with a posted speed limit below 80km/hour. Indeed, for single vehicle crashes, cross tabulation of just two of the critical definitional factors – critical event times and posted speed zone – showed that:

- n=390 (28.3%) single vehicle crashes identified by police to involve fatigue occurred on *80km/hour plus zone roads* but *outside the critical event times*
- n=160 (11.6%) single vehicle crashes identified by police to involve fatigue occurred *within critical event times* but *on < 80km/hour zone roads*

Thus, time and speed zone factors appear to have been particularly critical to the limited correspondence between police and ATSB identified fatigue-related crashes.

7. DISCUSSION

7.1 Introduction

The overall aim of this investigation was to further understand the contribution of fatigue to motor vehicle crashes in Western Australia, particularly those resulting in death or serious injury. This was addressed through the comparative analysis of police reported fatigue-related crashes and the application of the Australian Transport Safety Bureau's operational definition to identify fatigue-related crashes occurring during the years 2009-2013. The findings of the above examination are discussed below, followed by recommendations for the reporting of fatigue and potential countermeasures.

7.2 The assessment and reporting of fatigue in Western Australia

Based on the findings of the analysis of the State's primary database of police reported crashes - the Integrated Road Information Systems managed by Main Roads Western Australia – there is good reason to conclude that fatigue as a contributing factor in road crashes in Western Australia is under-assessed and potentially under-reported. Just over one in three of all police attended crashes and a similar proportion of all killed and serious injury (KSI) crashes recorded in IRIS for the period 2009-2013 included a report on the involvement of fatigue. Despite these findings, it was encouraging to note that the annual proportion of police attended crashes that were assessed for fatigue had at least remained relatively stable over the five-year period of the investigation, averaging around 3,350 assessments per year.

Further investigation is nevertheless required to determine why so few police attended crashes, particularly those resulting in death or serious injury, are provided with a fatigue report. It may perhaps be because of limited training, resources or opportunity to investigate the potential contribution of fatigue, or because an investigation of fatigue seems unwarranted if there is evidence or information to suggest other potential contributing factors such as speed or alcohol

The likely under-assessment of fatigue by police is a limiting factor in the understanding of the size and nature of the problem and thus, the development of targeted countermeasures. Hence there is a need for the application of a post-crash proxy measure to supplement the assessment of fatigue. Ideally this should be a nationally standardised measure to facilitate harmonisation across Australian jurisdictions, as per the recommendation recently proposed by CARRS-Q (2015) and the National Transport Commission (NTC) (2016). Indeed, the National Transport Commission (2016) final report into fatigue and heavy vehicles recommends that Austroads manage a National Road Safety Strategy project in conjunction with the NTC, local road agencies and police to "..review and agree national harmonised processes" (page 22) for the assessment and reporting of fatigue.

7.3 The incidence and characteristics of fatigue-related crashes in Western Australia

7.3.1 Incidence

Notwithstanding the potential under-assessment and under-reporting of fatigue, the incidence over the period 2009-2013 was noted to be around 10% for all crashes assessed by police or 0.90% when considered as a proportion of *all reported crashes* (which includes those without an assessment by police of fatigue). The extrapolated population incidence is reasonably similar to the 1.3% determined from the application of the ATSB operational definition to *all reported crashes*. When the number of police identified and ATSB defined fatigue-related crashes are combined (minus the n=265 crashes that were commonly identified as fatigue-related), the proportion of *all reported crashes* is closer to 2% for the five-year period of investigation. Further to this, the analysis of the annual incidence of both police and ATSB defined fatigue-related crashes adjusted for the number of licensed drivers and registered vehicles indicated that fatigue as a contributing factor in crashes had remained stable over the period of investigation.

Consistent with the reporting in other jurisdictions, the incidence of fatigue was found to significantly vary with the injury severity of the crash. Based on the assessments by police and the application of the ATSB definition, the proportion of *all reported KSI crashes* judged to involve fatigue for the period varied between 4.5% and 5.5% respectively and 9% after combining the two respective assessments. Indeed, the highest incidence of fatigue was reported for crashes resulting in a fatality, ranging from 19.2% for police attended crashes to 12.3% for ATSB defined cases. After combining the number of fatal crashes judged to involve fatigue (minus n=15 that were commonly reported), it is estimated that approximately 17.5% of *all reported fatal crashes* for the period were fatigue-related. This figure approximates the annual incidence reported for New South Wales (16.5% in 2014) and is somewhat higher than that reported for New Zealand (13%) and Queensland (11.5% in 2015) and is nearly seven times higher than the 2.6% of fatalities for the USA reported by NHTSA (2016).

It must be borne in mind that some of the observed difference in the incidence of fatigue with the aforementioned jurisdictions may be due to variations in the assessment of fatigue involvement in a crash. For example, both New South Wales and Queensland utilise a combination of police assessments *and* a post-crash proxy measure (which are variations of the ATSB operational definition examined in this study). Thus, it is reasonable to expect that the incidence across jurisdictions will continue to vary to lesser and greater degrees until a more standardised, uniform approach to the determination of fatigue in crashes is introduced.

7.3.2 Characteristics of fatigue-related crashes and drivers

The findings from the investigation of the assessment of fatigue by WA Police and from the application of the ATSB operational definition showed many similarities and some differences in regards to the characteristics of fatigue-related crashes and drivers. A summary discussion of the most significant findings is presented below.

Injury Severity

As noted above, there was strong evidence from the examination of both measures that the incidence and risk of fatigue is associated with the level of injury severity, with crashes resulting in death followed by hospitalisation having the higher odds of fatigue involvement compared with crashes that result in minor injury or property damage only. This finding is supportive of the variations in the incidence of fatigue among fatal and other injury and non-injury outcomes observed in New Zealand (New Zealand Ministry of Transport, 2015) and New South Wales (NSW Centre for Road Safety, 2015).

The noted difference between the two measures however, was in relation to the calculated odds for fatigue associated with these injury severities. For example the odds of a fatal crash involving fatigue as identified by the ATSB definition was nearly six times that identified from police reports of fatigue (relative to the incidence in minor injury and property damage only crashes). This finding is most likely due to the application of the ATSB definition to a significantly greater number of minor injury/property damage only crashes - compared with that investigated by police - of which a much smaller proportion were defined to involve fatigue. The higher risk of fatigue associated with killed and serious injury crashes identified by both police and the ATSB definition highlights the need for a close and fuller examination of the local KSI crashes to determine the involvement of fatigue.

Region and Speed Zone

Both assessments similarly noted that crashes occurring in the non-metropolitan area were most likely to be identified as fatigue-related. In the case of police assessed crashes the increased odds of a Regional WA crash involving fatigue was nearly two-fold compared with 10-fold from the application of the ATSB definition. It is reasonable to expect that some of the increased risk associated with a regional crash is associated with higher speed zones in these areas, a finding previously identified by Haworth and Rechnitzer (1993). Indeed 47.5% of police reported fatigue-related crashes in this study were noted to occur in speed zones ≥100km/hour and that crashes on these roads were 5.5 times more likely to be judged to involve fatigue compared with crashes in ≤50km/hour zones. The New Zealand Ministry of Transport (2016) concluded that the higher incidence of fatigue on higher speed zone roads helps explain why fatigue-related crashes often result in more serious injury.

The relationship between the region and speed zone and injury outcome associated with fatigue highlights the need for effective countermeasures measures in regional and remote areas to reduce the likelihood and severity of injury associated with fatigue-related crashes such as run off road excursions. Earlier Western Australian research showed that countermeasures such as sealed shoulders and audible edgelines, which aim to reduce the likelihood of drivers running of the road, have been shown to be effective in the reduction (79%) of casualty crashes (Meuleners & Hendrie, 2009). More recently, a review of the effectiveness of treatments undertaken for the state's Rural Run off Road Crash Program also found that treatments such as the widening and sealing of shoulders and the installation of audible edgelines produced a 26% reduction in run off road killed and serious injury crashes (Chow, Meuleners & Wong, 2016).

The above findings highlight the need for an in-depth examination of the road infrastructure around crashes identified to involve fatigue to assess the need for the application of such treatments. This recommendation is particularly pertinent to crashes in the Wheatbelt region which evidenced the highest proportion (ranging between 21.9% and 11.8%) and odds of fatigue involvement of all regional areas for the period of investigation. The increased odds of a fatigue-related crash in this region (relative to metropolitan Perth) ranged between 3.3 (for police assessed crashes) to 23.9 (for ATSB defined crashes).

Crash Type

As identified in the review of the published literature (Section 3.2.1), single vehicle run off road crashes evidence the highest incidence of fatigue involvement relative to those involving multiple vehicles (e.g., Haworth & Rechnitzer, 1993; Tefft, 2012). Head-on crashes are the next most common type of fatigue-related crash (New Zealand Ministry of Transport, 2015). This study's findings of the analysis of police reported crashes support those reported in the literature. It was found that 73% of fatigue-related police reported crashes were single vehicle in nature (e.g., hit object; non-collision) and that this category of crash was four time more likely than multiple vehicle crashes to involve fatigue. Though the ATSB operational definition was concerned with only single vehicle crashes and head-on crashes (not involving overtaking), the former nevertheless accounted for 78% of crashed identified to involve fatigue. The predominance of single vehicle crashes among those assessed and defined to involve fatigue further highlights the need for countermeasures to reduce the likelihood of vehicles leaving the road, such as those described above, and secondly, other countermeasures such as cleared roadsides and effective barriers to reduce the severity of injuries should the fatigued driver fail to take effective action.

Vehicle Type

A large body of fatigued driving research has been concerned with the risk associated with drivers of commercial vehicles, particularly trucks and heavy vehicles. Consequently there has been a strong focus on the implementation of regulations and schemes to reduce the incidence of fatigue across the industry (National Transport Commission, 2016). Previous reports indicate that fatigue is twice as likely to be involved in the fatal crashes of heavy vehicle drivers compared with crashes involving other drivers (Dobbie, 2002). However, this study provided mixed evidence of a higher risk of fatigue among drivers of trucks and heavy vehicles. For single vehicle crashes, drivers of trucks and heavy vehicles accounted for 6% and 8% of fatigue-related crashes reported by police and identified by the ATSB definition respectively. However, based on police reports, drivers of trucks and heavy vehicles were *not* significantly more likely than drivers of motorcars to be fatigued. In contrast, analysis of the ATSB defined single vehicle fatigue crashes showed that drivers of trucks and heavy vehicles were 1.4 and 2.5 times respectively more likely than drivers of motorcars to be fatigued. Further analysis of the involvement of trucks and heavy vehicles in fatigue-related multiple vehicle crashes showed they accounted for between 6.7% (police report) and 16.8% (ATSB identified) of all vehicles involved. These findings suggest that the application of the ATSB definition is more sensitive to the identification of fatigue-related crashes that involve trucks and heavy vehicles. This could be because of the applied strict time criteria for single vehicle crashes, particularly midnight to 6.00am, during which a high proportion of single vehicle truck crashes are noted to occur (Dobbie, 2002).

Other research has highlighted the problem of fatigue in the heavy vehicle transport industry within Western Australia. A recent report by the National Truck Accident Research Centre (2015) noted that Queensland followed by Western Australia was the worst performing jurisdiction in Australia for major crash incidents in 2013 and that Western Australia evidenced the highest proportion of incidents attributed to fatigue (30%). There are a variety of reasons why fatigue features strongly in the crashes of truck and heavy vehicle drivers and these may partly explain the incidence in Western Australia. Heavy vehicle drivers are known to drive long distances on high speed roads under time pressures and for extended periods of time (May, 2011), often without adequate rest in between (Arnold et al., 1996; National Transport Commission, 2016), with some of their increased risk due to particular employment conditions within the heavy vehicle driving industry (Williamson & Friswell, 2013) and even medical conditions such as Obstructive Sleep Apnoea (Meuleners & Fraser, 2012). The National Transport Commission (2016) had declared that driver fatigue in the heavy vehicle transport industry represents an ongoing policy challenge. Unfortunately, a full examination of these issues in relation to fatigue and the heavy vehicle transport industry in Western Australia is beyond the immediate scope of this report.

Time of Day

Findings from the analysis of police assessed crashes showed a very clear trend of a higher incidence of fatigue-related crashes during the period midnight to 6.00am. Crashes during this time accounted for 30% of all fatigue-related crashes but only 9.7% of crashes assessed by police not to involve fatigue. Around one-quarter of crashes during this time were judged to involve fatigue, with substantially increased odds (3.6 times) of the crash being fatigue-related (compared with those occurring 6.00pm to 11.59pm). Further analysis of single vehicle crashes revealed a very strong time of day effect with 46.5% of single vehicle crashes identified by police to involve fatigue occurring within the critical ATSB time periods of 2.00pm-4.00pm and midnight to 6.00pm. Indeed crashes during these periods were 31% and 3.2 times more likely to involve fatigue compared with those occurring 6.00pm to 11.59pm. These findings provide support for the belief that driving during these time periods may be sensitive to circadian rhythm effects and the effects of extended wakefulness as described by Connor (2009). These findings are generally supportive of those reported elsewhere which have noted a higher incidence of fatigue crashes during the period that extends from 10.00pm until 6.00am (e.g., Armstrong et al., 2008; Tefft, 2012) followed by a somewhat lower incidence between 2.00pm and 4.00pm (Chipman & Jin, 2009).

Driver Age and Sex

The risk of fatigued driving associated with driver age and sex was investigated for single vehicle crashes only. There were inconsistent findings for driver sex. While both measures showed that males accounted for around 70%-72% of crash involved fatigued drivers, only police reports showed that males were significantly more likely (OR=1.23) than females to be involved in a fatigue-related crash. These mixed findings provide only partial support the findings of other research which have noted that males are more likely than females to be involved in fatigue-related crashes (e.g., Filtness et al., 2015; Tefft, 2012).

In relation to driver age, there were mixed findings again and support for the previously reported increased risk of fatigue driving among younger age drivers (Dobbie, 2002; Tefft, 2012 Armstrong et al., 2008; Mitchell et al., 2015; Filtness et al., 2015). In this study, drivers under 24 years of aged evidenced the *lowest* proportions of ASTB identified fatigue-related crashes, with the highest incidence noted for those age 60-69 years. This age group were 1.6 times more likely to be involved in a fatigue related crash compared with those aged 15-19 years. In contrast, the findings from police reported crashes were consistent with the finding of other research; it was noted that drivers aged 20-24 years evidenced the highest incidence of fatigue, being twice as likely as those aged 15-19 years to be fatigued. The inconsistencies in these findings require further investigation to tease out possible out interactions with time of day, type of crash and driving exposure factors such as locations and type of road (i.e., speed zone).

7.4 Correspondence of the assessment by Western Australian Police and the application of the Australian Transport Safety Bureau operational definition to identify fatigue-related crashes

The correspondence analysis revealed that only 16.1% of crashes of all injury severities reported by WA Police to involve fatigue were similarly defined as fatigue-related by the ATSB operational definition. This is considerably lower than the 46.5% reported by Dobbie (2002) based on the 1998 population of Australian fatal crashes with accompanying police and coroner records. In the current study the degree of correspondence improved to near 30% when fatal crashes only were considered, though these were few in number (n=286) compared with the 1,511 examined by Dobbie (2002). It is interesting to note however, that a very high level of correspondence was observed for the identification of crashes determined *not to be fatigue-related*, ranging between 91.3% and 96.4%. This finding is consistent with that reported by Dobbie (2002) who noted 85% of crashes judged *not to involve fatigue* from police and coroner reports were similarly judged *not to involve fatigue* from the application of the ATSB definition. Both studies have thus highlighted that police and the ATSB definition are better at mutually discerning what is *not a fatigue-related* crash rather than *what is a fatigue-related crash*.

The correspondence in the identification of fatigue-related crashes in the current study is related to the mutual identification of crashes that were single vehicle in nature and occurred during the specified times of midnight to 6.00am or 2.00pm to 4.00pm or were head-on crashes (with overtaking). Conversely, over eight in ten crashes assessed by police to involve fatigue were characterised by crash and/or driver factors inconsistent with the inclusion or exclusion criteria of the ATSB definition. Most recently, the National Transport Commission 2015) commented that the ATSB definition "..carves out too many fatigue-related crashes" (page 34), particularly because of time and speed zone restrictions. The lack of correspondence should not be interpreted to suggest that one or the other measure is the more valid and reliable – that was not the aim of the investigation – but that each measure utilises differing defining and assessment criteria which together might provide a better estimate of the involvement of fatigue. For example, in this study, around 17.5% of *all reported fatal* *crashes* for the period were estimated to involve fatigue when the identifications from the two measures were combined.

Findings from the analysis of the group of crashes judged by police to involve fatigue but outside the scope of the ATSB definition supports the concerns of other researchers (Armstrong et al. 2008; Armstrong et al., 2011) regarding the need to expand the criteria for a proxy definition for fatigue crashes to times beyond the traditionally defined critical event periods (for single vehicle crashes) and to include roads with speed zones below 80km/hour. This investigation showed that at least 28.3% of police reported fatigue crashes excluded by the ATSB definition were single vehicle in nature and occurred on 80km/hour and higher roads but occurred outside the critical event times of midnight to 6.00am or 2.00pm to 4.00pm. In addition to this, a further 11.6% were single vehicle crashes that occurred within the critical event times but were excluded because they occurred on roads with speed zones below 80km/hour.

The origins of the aforementioned critical event times include the findings of early sleep research into wake-rest circadian rhythm cycles and road traffic studies that identified a higher proportion of fatigue-related crashes during these cycle times (Chipman & Jin, 2009; Connor, 2009; Folkard, 1997). However, drowsy or sleepy driving can be influenced by other factors besides circadian rhythm changes, including clinical sleep disorders (Johns, 2000; Meuleners & Fraser, 2012) and extended periods of prior wakefulness and reduced sleep quality (Williamson et al., 2011).

Extended wakefulness and reduced sleep quality are a particular concern given the changing nature of employment and work patterns toward shift work - which is associated with a number of well-known health and cognitive effects - to accommodate increased production and the provision of essential services over a 24-hour period (Australian Bureau of Statistics, 2014). Near one in five working Australians now undertakes shift work (i.e., outside 6.00am to 6.00pm) (Australian Bureau of Statistics, 2014). Thus 20% of the Australian working population is potentially at risk of known shift work associated sleep difficulties such as trouble getting to sleep and shortened sleep (Akerstedt, 2003; Kazemi, Haidarimoghadam, Motamedzadeh, Golmohamadi, Soltanian & Zoghipaydar, 2016), drowsiness during and outside of work (Akerstedt, 2003); as well as disruption of the circadian wake-rest cycle (Rajaratnam, Howard & Grunstein, 2013). These disturbances have the potential to affect the alertness and cognitive performance of a select group of drivers across other times of the day beyond the critical event times proposed by the ATSB operational definition. Indeed, 65% of single vehicle crashes identified by WA Police to involve fatigue occurred outside the ATSB defined critical event times of midnight-6.00pm and 2.00pm-4.00pm. This figure is somewhat higher than the 47% of police reported single vehicle fatigue-related crashes occurring at non-critical times reported by Filtness et al. (2015). Collectively, these findings suggest that single vehicle crashes outside the critical times can involve fatigue and that the proposed critical event times should merely serve as a guide in the assessment of fatigue (perhaps when no other 'causal' factor such as alcohol, other drugs, or suicide can be identified or presumed) rather than a non-negotiable criterion for exclusion.

The speed zone restriction of the ATSB definition similarly affected the correspondence between the two measures. It has been called to question (Armstrong et al., 2008) as it stipulates that fatigue is less likely to be a causal factor in crashes that occur on road with speed zones below 80km/hour. This study noted that 38.9% of police reported fatigue-related crashes occurred on roads with posted speed limits below 80km/hour. This proportion is similar to that reported by Armstrong et al. (2013), though the latter finding was based on self-reports of fatigue or sleep related incidents and not police crash reports. While the consequence of fatigue driving may indeed be more severe in higher speed zones because of (potentially) longer driving distances and higher travel and impact speeds, a 24-hour society and an increasing proportion of shift workers may increase the likelihood of fatigue contributing to crashes in urban, built up areas with lower speed zones.

Higher traffic volumes associated with lower speed zone urban areas also means there is a higher likelihood that a fatigue-related crash will be multivehicle in nature, other than a head-on collision which is the only multiple vehicle crash type included under the ATSB operational definition. In this study, nearly 25% of crashes reported by police to involve fatigue were neither single vehicle or head-on, with nearly three-quarters being rear end or right-angle crashes – crashes that predominate in the lower speed urban, metropolitan area (Palamara, Kaura & Fraser, 2013). As fatigue is well known to affect the alertness, reaction time and decision making of drivers (Philips, 2015), there is good theoretical reason at the very least to believe that fatigue could be a risk factor when negotiating urban area roads and contribute to the types of crashes that characterise these lower speed urban-metropolitan area roads.

Finally, the findings of this study merit some discussion of the role of alcohol in potential fatigue-related crashes. The ATSB operational definition automatically excludes crashes where driver alcohol readings are ≥0.05gm%. This is presumably because in such cases, alcohol would be deemed to be the main contributing factor and one that overrides any potential impact of fatigue. Similarly, the Queensland and New South Wales post-crash proxy measure definitions would also exclude fatigue as a contributing factor if alcohol is deemed to be involved (though these proxies do not specify a particularly BAC level). In this study, 20% of the 1,379 police reported fatigue-related crashes that were excluded by the ATSB definition involved a driver with a BAC ≥0.05gm%. It is debateable whether this is an appropriate assessment of the contribution of fatigue by police given the involvement of alcohol.

In relation to this point, researchers such as Philip, Vervialle, Le Breton, Taillard & Horne (2001) have examined the co-relationship of alcohol and driver fatigue (using the applied definition proposed by Horne and Reyner, 1995) in a five-year population of French road crashes. They concluded that fatigue, when combined with alcohol, is associated with a high risk of death (OR=6.8) and was higher than that for alcohol alone (OR=4.2) or fatigue alone (OR=1.65). These findings highlight the multifactorial nature of risk for crash involvement and injury and provide some legitimacy to the co-reporting of fatigue and other risk factors such as alcohol, as was done in this study where 20% of fatigue-related single vehicle crashes involved a driver with a BAC ≥0.05gm%. The bigger question however, is whether fatigue can be easily determined by attending police when alcohol is present, particularly since there is good evidence to suggest that the performance decrements associated with fatigue can be similar, on some behaviours, to those for alcohol (Williamson, Feyer, Mattick, Friswell & Finlay-Brown, 2001).

7.5 Summary and Recommendations

This research has identified that around a third of *all police attended crashes* and a similar proportion of *all recorded KSI* crashes for the period 2009-2013 included a report by police on the involvement of fatigue. The adjusted annual incidence of fatigue for both police reports and the application of the ATSB definition were found not to have significantly varied over this time. When the number of fatigue-related crashes identified from both measures is combined, up to 2% of *all reported crashes* for the period may be fatigue-related. The combined proportion is even higher for *all reported KSI crashes* (9%) and higher still when only fatal crashes are considered (17.5%). These proportions vary somewhat with those reported elsewhere in Australia and New Zealand. A comparison of the findings of the analysis of police reported fatigue crashes and ATSB defined fatigue crashes showed that fewer than one in five crashes judged by police to be fatigue-related were similarly identified from the application of the ATSB definition. However, the correspondence was increased to nearly 30% for fatal crashes and t0 20% for those occurring in Regional WA. This suggests that the proxy measure might be more relevant and applicable for this level of crash severity, particularly if it occurs in the non-metropolitan region. The findings also highlight the need to revise the proxy measure to make it more inclusive of fatigue-related crashes that occur at other high risk times, in lower speed zones, and involve other crash types.

The crash and driver characteristics identified from the analysis of police reports and the application of the ATSB definition also suggested a level of comparability between the measures as both identified similar risk factors for a fatigue-related crash that were generally supportive of those identified from a review of the literatures. From both measures, the reporting and identification of fatigue was significantly and reasonably consistent in relation to the injury severity of the crash, the region, speed zone and time of day of the crash, and the crash type. There was however, less consistent evidence across the measures for the risk of a fatigue-related crash associated with driver sex and age and vehicle type.

The findings of this investigation suggest a number of possible recommendations:

4. *That Western Australian Police investigate the range of factors that might be contributing to the low level of assessment of fatigue by officers who attend traffic crashes.*
5. *That Western Australia collaborates with national stakeholders to develop a national, standardised definition for the measurement and reporting of fatigue as a contributing factor in crashes, and that this measure be applied post-crash to supplement the reporting of fatigue by police.*
6. *That further research is undertaken of select serious injury fatigue-related crashes to investigate their relationship with road infrastructure factors, particularly in high risk regional locations such as the Wheatbelt.*

8. REFERENCES

Akerstedt, T. (2003. Shift work and disturbed sleep/wakefulness. *Occupational Medicine*, *53*, 89-94.

Armstrong, K., Filtness, A., Watling, C., Barraclough, P., & Haworth, N. (2013). Efficacy of proxy definitions for identification of fatigue/sleep related crashes: An Australian evaluation. *Transportation Research Part F*, *21*, 242-252. http://dx.doi.org.10.1016/j.trf.2013.10.002

Armstrong, K., Haworth, N. Watling, C., & Trenorden. J. (2011). *Improving the identification of fatigue-related crashes in the Australian Capital Territory*. Queensland University of Technology, Queensland: Centre for Accident Research and Road Safety – Queensland.

Armstrong, K., Smith, S. Steinhard, D., & Haworth, N. (2008). *Fatigue crashes happen in urban areas too: Characteristics of crashes in low speed urban areas.* Paper presented to the Australasian Road Safety Research, Policing and Education Conference, November 2008, Adelaide, South Australia.

Arnold, P., Hartley, L., Corry, A., Hochstadt, D., Penna, F., Feyer, A. (1997). Hours of work, and perceptions of fatigue among truck drivers. *Accident Analysis and Prevention*, *29* (4), 471–477.

Australian Bureau of Statistics (2010). *Australian labour market statistics, October 2010 Shift Workers* (No. 6105.0). Retrieved from http://www.abs.gov.au/ausstats/abs@.nsf/featurearticlesbyCatalogue/5461A9DAE97FF759CA2578C300153388?OpenDocument

Beanland, V., Fitzharris, M., Young, K., & Lenne, M. (2013). Driver inattention and driver distraction in serious casualty crashes: Data from the Australian National In-depth Study. *Accident Analysis and Prevention*, *54*, 99-107. http://dx.doi.org.10.1016/j.aap.2012.12.043

CARRS-Q (2015). *Sleepiness and fatigue*. Retrieved from http://www.carrsq.qut.edu.au/publications/corporate/fatigue_fs.pdf. 8th December 2016.

Chipman, M. & Jin, Y., (2009). Drowsy drivers: The effect of light and circadian rhythm on crash occurrence. *Safety Science*, *47*, 1364-1370. doi:10.1016/j.ssci.2009.03.005.

Connor, J. (2009). The role of driver sleepiness in car crashes: A review of the epidemiological evidence. In J.C. Verster, S.R. Pandi-Perumal, J.G. Ramaekers and J.J de Gier (Eds.), *Drugs, driving and traffic safety* (187-205). Switzerland: Birkhauser Verlag.

Crummy, F., Cameron, P., Swann, P., Kossman, T., & Naughton, M. (2008). *Internal Medical Journal*, *38*, 769-775. doi;10.1111/j.1445-5994.2008.01629.x

Di Milia,L., Smolensky, M., Costa, G., Howarth, H., Ohayon, M., & Philip, P. (2011). Demographic factors, fatigue, and driving accidents: An examination of the published literature. *Accident Analysis and Prevention, 43*, 516-532. doi:10.1016/j.aap.2009.12.018

Dobbie, K. (2002). *An analysis of fatigue-related crashes on Australian roads using an operational definition of fatigue*. Canberra, ACT: Australian Transport Safety Bureau. OR 23

Expert panel on driver fatigue and sleepiness. (1997). *Drowsy Driving and Automobile Crashes*. Washington DC: National Centre for Sleep Disorders Research/National Highway Traffic Safety Authority.

Ferguson, S., Paech, G., Sargent, C., Darwent, D., Kennaway, D., & Roach, G. (2012). The influence of circadian time and sleep dose on subjective fatigue ratings. *Accident Analysis and Prevention*, *45S*, 50-54. doi:10.1016/j.aap.2011.09.026

Filtness, A.J., Armstrong, K.A., Watson, A., Smith, S.S. (2015). Sleep-related crash characteristics: Implication for applying a fatigue definition to crash reports. *Accident Analysis and Prevention*, xx, xx-xx. http://dx.doi.org/10.1016/j.aap.2015.11.024

Folkard, S. (1997). Black times: Temporal determinants of transport safety. *Accident Analysis and Prevention*, *29*, 417-430.

Gordon, C.P & Regan, M.A. (2013). Driver distraction and inattention and their role in crashes and safety-critical events. In M. A. Regan, J.D Lee and T.W. Victor (Eds.), *Driver distraction and inattention: Advances in Research and Countermeasures Volume 1* (157-170). Surrey, England: Ashgate Publishing Limited.

Hancock, P. (2103). Driven to distraction and back again. In M. A. Regan, J.D Lee and T.W. Victor (Eds.), *Driver distraction and inattention: Advances in Research and Countermeasures Volume 1* (9-25). Surrey, England: Ashgate Publishing Limited.

Hatfield, J., Friswell, R., & Williamson, A. (2015). *Road crash injuries: Costs and prevention*. Sydney, New South Wales: Austroads Ltd. SS1494

Haworth, N. & Rechnitzer, G. (1993). *Description of fatal crashes involving various causal variables*. Canberra, Australia: Federal Office of Road Safety. CR119.

Horne, J., & Reyner, L. (1995). Sleep related vehicle accidents. *British Medical Journal*, *6979*, 565–567.

Jackson, P., Hildtich, C., Holmes, A., Reed, N., Merat, N., & Smith, L. (2011). *Fatigue and road safety: A critical analysis of recent evidence*. London: Department of Transport. Road Safety Web Publication No.21.

Johns, M., Chapman, R., Crowley, K., Tucker, A. (2008). A new method for assessing the risks of drowsiness while driving. *Somnologie*, *12*, 66-74. Doi 10.1007/s11818-0080330-3

Jordan, A., McSharry, D. & Malhotra, A. (2014). Adult obstructive sleep apnoea. *Lancet*, *383*, 736-747. http://dx.doi.org/10.1016/S0140-6736(13)60734-5

Kazemi, R., Haidarimoghadam, R., Motamedzadeh, M., Golmohamadi, R., Soltanian, A. & Zoghipaydar, M. (2016). Effects of shift work on cognitive performance, sleep quality, and sleepiness among petrochemical control room workers. *Journal of Circadian Rhythms*, *14*, 1-8.

Kilpelainen, M., Radun, I., & Summala, H. (2005). *Testing fitness-to-drive of sleepy drivers: Pilot studies in field and laboratory settings*. Helsinki, Finland: LINTU Research Program, Report 7/2005.

Lennė. M. Triggs, T., & Redman, J. (1998). Interactive effects of sleep deprivation, time of day and driving experience on a driving task. *Sleep*, *21*, 38-44.

May, J. (2011). Driver fatigue. In B. Porter (Ed.), *Handbook of traffic psychology* (287-297). doi: 10.1016/B978-0-12-381984-0.10021-9

May, J., & Baldwin, C. (2009). Driver fatigue: The importance of identifying causal factors of fatigue when considering detection and countermeasure technologies. *Transportation Research Part F*, *12*, 218-224. do1:10.1016/j.trf.2008.11.005

Meuleners, L. & Fraser, M. (2012). *The heavy vehicle study report: Results from Western Australia.* Perth, Western Australia: Curtin-Monash Accident Research Centre.

Meuleners, L., Fraser, M., Govorko, M., & Stevenson, M. (2015). Determinants of the occupational environment and heavy vehicle crashes in Western Australia: A case-control study. *Accident Analysis and Prevention*, *xx*, xxx-xxx. http://dx.doi.org/10.1016/j.aap.2015.11.023

Meuleners, L., & Hendrie, D. (2009). *An evaluation of the effectiveness and cost-effectiveness of sealed shoulders and audible edgelines on Albany Higway,* *2000-2004*. Perth, WA: Centre for Population Health Research, Curtin University.

Mitchell, R., Senserrick, T., Bambach, M., & Mattos, G. (2015). Comparison of novice driver and full licensed driver common crash types in New South Wales, 2001-2011. *Accident Analysis and Prevention*, *81*, 2014-210. http://dx.doi.org/10.1016/j.aap.2015.04.039

Monk, T., Weitzman, E., Fookson, J., Moline, M., Kronauer, R., & Gander, P., (1983). Task variables determine which biological clock controls circadian rhythms in human performance. *Nature*, *304* (5926), 543–545.

National Transport Commission (2015). *Developing a heavy vehicle fatigue data framework: Discussion Paper*. Melbourne: Author.

National Transport Commission (2016). *Heavy vehicle driver fatigue*. Melbourne: Author.

National Truck Accident Research Centre. (2015). *Major accident investigation report: Covering major accidents in 2013*. Brisbane: National Transport Insurance.

National Highway Transportation Safety Administration. (2000). *Drowsy Driving and Automobile Crashes: NCSDR/NHTSA Expert Panel on Driver Fatigue and Sleepiness.* National Center on Sleep Disorder Research, National Highway Safety Administration, Washington.

New South Wales Centre for Road Safety. (2016). *Definitions and notes to support road crash data*. Transport for New South Wales, NSW Government.

New Zealand Ministry of Transport. (2015). *Fatigue 2015*. New Zealand: Ministry of Transport, New Zealand Government. Retrieved July 2016 from http://www.transport.govt.nz/assets/Uploads/Research/Documents/Fatigue-2015.pdf

NHTSA.http://www.nhtsa.gov/Driving+Safety/Drowsy+Driving/Research+on+Drowsy+Driving.

Pack, A., Pack, A., Rodgman, E., Cucchiara, A., Dinges, D., & Schwab, C. (1995). Characteristics of crashes attributed to the driver having fallen asleep. *Accident Analysis and Prevention*, *27*, 769-775.

Palamara, P., Kaura, K., & Fraser, M. (2013). *An investigation of serious injury motor vehicle crashes across metropolitan, regional and remote Western Australia*. Perth, Western Australia: Curtin-Monash Accident Research Centre. RR 09-001.

Philip, P., Vervialle, F., Le Breton, P., Taillard, J., & Horne, J. (2001). Fatigue, alcohol, and serious road crashes in France: Factorial study of national data. *British Medical Journal*, *322*, 829.

Phillips, R. (2015). A review of definitions of fatigue – And a step toward a whole definition. *Transportation Research Part F*, *29*, 48-56

Radun, I. (2009). *Fatigued driving: Prevalence, risk factors and groups, and the law*. Unpublished Dissertation. Helsinki, Finland: University of Helsinki.

Radun, I., Ohisalo, J., Radun, J., Wahde, M., Kecklund, G. (2013). Driver fatigue and the law from the perspective of police officers and prosecutors. *Transportation Research Part F*, *18*, 159-167. http://dx.doi.org/10.1016/j.trf.2013.01.001

Radun, I., & Radun, J. (2009). Convicted of fatigue driving: Who, why and how? *Accident Analysis and Prevention*, *41*, 869-875. doi:10.1016/j.aap.2009.04.024

Radun, I., & Summala, H. (2004). Sleep-related fatal vehicle accidents: Characteristics of decisions made by multidisciplinary investigation teams. *Sleep*, *27*, 224-227.

Rajaratnam, S., Howard, M., & Grunstein, R. (2013. Sleep loss circadian disruption in shift work: health burden and management. *Medical Journal of Australia*, *199*, S11-S15.

Sagaspe, P., Taillard, J., Bayon, V., Lagarde, E., Moore, N., Boussuge, J., Chaumet, G., Bioulac, B., Philip, P. (2010). Sleepiness, near-misses and driving accidents among a representative population of French drivers. *Journal of Sleep Research*, *19*, 578-584. DOI: 10.1111/j.1365-2869.2009.00818.x

Shen, J., Barbera, J., & Shapiro, C. (2006). Distinguishing sleepiness and fatigue: Focus on definition and measurement. *Sleep Medicine Reviews*, *10*, 63-76. DOI:10.1016/j.smrv.2005.05.004

Stevenson, M., Elkinton, J., Sharwood, L., Meuleners, L., Ivers, R., Boufous, S., Williamson, A., Haworth, N., Quinlan, M., Grunstein, R., Norton, R., & Wong, K. (2014). The role of sleepiness, sleep disorders, and the work environment on heavy-vehicle crashes in 2 Australian states. *American Journal of Epidemiology*, *179*, 594-601. DOI: 10.1093/aje/kwt305

Stutts, J., Wilkins, J., Osberg, J., Vaughn, B. (2003). Driver risk factors for sleep-related crashes. *Accident Analysis and Prevention*, *35*, 321-331.

Tefft, B. (2010). *Asleep at the wheel: The prevalence and impact of drowsy driving*. Washington DC: AAA Foundation for Road Safety.

Tefft, B. (2012). Prevalence of motor vehicle crashes involving drowsy drivers, United States, 1999-2008. *Accident Analysis and Prevention*, *45*, 180-186. doi:10.1016/j.aap.2011.05.028

Treager, S., Reston, J., Schoelles, K., & Phillips,B. (2009). Obstructive sleep apnoea and risk of motor vehicle crash: Systematic review and meta-analysis. *Sleep Medicine*, *5*, 573-581.

VicRoads (2016). *2015 Victorian Road Trauma: Analysis of fatalities and serious injuries*. Updated 5th May 2016. Victoria State Government.

VicRoads Fatigue Statistics. https://www.vicroads.vic.gov.au/safety-and-road-rules/driver-safety/fatigue/fatigue-and-road-safety). Accessed 21st November 2016.

Watling, C., Armstrong, K., & Radun, I. (2015). Examining signs of sleepiness, usage of sleepiness countermeasures and the associations with sleepy driving behaviours and individual factors. *Accident Analysis and Prevention*, *85*, 22-29. http://dx.doi.org/10.1016/j.aap.2015.08.022

Willamson, A., Freyer, A., Mattick, R., Friswell, R., & Finlay-Brown, S. (2001). Developing measures of fatigue using an alcohol comparison to validate the effects of fatigue on performance. *Accident Analysis and Prevention*, *33*, 313-326.

Willamson, A., Freyer, A., & Friswell, R. (1996). The impact of work practices on fatigue in long distance truck drivers. *Accident Analysis and Prevention*, *28*, 709-719.

Willamson, A. & Friswell, R. (2011). Investigating the relative effects of sleep deprivation and time of day on fatigue and performance. *Accident Analysis and Prevention*, *43*, 690-697. doi:10.1016/j.aap.2010.10.013

Williamson, A. & Friswell, R. (2013). The effect of external non-driving factors, payment type and waiting and queuing on fatigue in long distance trucking. *Accident Analysis and Prevention*, *58*, 26-34. http://dx.doi.org/10.1016/j.aap.2013.04.017

Williamson, A., Lombardi, D., Folkard, S., Stutts, J., Courtney, T., & Connor, J. (2011). The link between fatigue and safety. *Accident Analysis and Prevention*, *43*, 498-515. doi:10.1016/j.aap.2009.11.011

Zhang, T. & Chan, A. (2014). Sleepiness and the risk of road accidents for professional drivers: A systematic review and meta-analysis of retrospective studies. *Safety Science*, *70*, 180-188. http://dx.doi.org/10.1016/j.ssci.2014.05.022