Comprehensive Review of Fatigue Research

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1.

1. FOREWORD

In order to obtain a comprehensive review of fatigue literature a wide variety of data bases, organisations and researchers had to be consulted. Below is list of the major sources of information obtained for this review:

Australian Road Research Board
Federal Office of Road Safety
National Aeronautics and Space Administration
National Transportation Safety Board
Monash University Accident Research Centre
Queensland Department of Transport
Road Traffic Authority
Transportation Research Board
Transportation Research Laboratories

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Over two hundred articles were collected and reviewed under the following headings

1. Fundamental factors
    - time on task
    - time of day
    - vigilance

1. Enforcement
    - curfew
    - prescriptive hours
    - fitness for duty
    - work schedules

1. Engineering solutions
    - driver monitors
    - vehicle monitors

1. Sleep factors & medical
    - apnoea
    - narcolepsy
    - sleep quality and quantity

1. Educational
    - driver training
    - progressive licenses
    - publicity

1. Road based Research

- edge lines
- rumble strips
- rest areas
- road design
- sealed shoulders
- road width

1.1 Definition

The issue of driver fatigue has gained increasing importance in the driving literature over the last 80 years. Driver fatigue and methods of counteracting its effects are now of primary importance to state and national transport departments, not only in W.A and Australia, but also in nations like the UK, USA and Canada with the expansion of markets.

The study of fatigue has increased in leaps and bounds, yet there is still no universal definition of fatigue. Researchers in this field have not been able to agree upon a single definition of fatigue, however, there is consensus amongst the scientific community that fatigue comprises of physiological, emotional and behavioural factors that can result in chronic physical or mental states. (Tyson 1992).

Nelson, (1989) perceives fatigue as a declarative state and defines fatigue "as the condition the person reaches as a result of sustained activity wherein he or she declares being unable to continue the activity further". Alternatively, Brown (1995) views fatigue as a progressive state and commences when a person believes that they are unable to perform the task at 100% efficiency, hence Brown defines fatigue as "a subjectively experienced disinclination to continue performing the task in hand because of perceived reductions in efficiency." Although both definitions differ they both agree on the fact that fatigue is a subjective experience with implications for the performance of the task.

1.2 Causes and mediators of driver fatigue

Brown (1995) in his review of the literature, identified three main causes of fatigue, these are (in order of importance), lack of sleep, time-of-day (circadian factors), and time on task. Brown also noted that these three factors rarely happen independently of each other and that they are interactive, that is, they impact on each other. To further complicate the issue, fatigue can be mediated by factors such as age, experience, physical fitness and the presence of sleep disorders or other medical conditions, personality, and also other factors such as the presence of drugs.

1.3 Measurement of driver fatigue

Driver fatigue can be measured in a myriad of ways and situations. Traditionally, the measurement of driver fatigue can be divided into 3 sections:

1. *Subjective measures/observational measures*: These methods of measurement usually comprise of techniques such as questionnaires/surveys, personal log books, diaries, changes in mood states, behaviour, changes in maximum voluntary control, endurance time.
2. *Performance Measures* : Performance measures of fatigue include measures such as ergographs, reaction time, lane position deviation, heading error, and general vigilance task measures.,
3. *Physiological measures*: Physiological measures of fatigue are becoming more reliable as advances in technology increases. Physiological indices of fatigue include measures of heart rate and core body temperature, electroencephalogram (ECG), electro-oculogram (EOG), and electromyogram (EMG) measures.

Measurement of fatigue may take place in a any number of situations. Usually, measurement takes place in laboratory settings using driving simulators which may incorporate both performance measures (reaction time, road heading error) and physiological measurements (EEG, EOG). Also, measurement can take place in field settings or in real driving situations.

2.

THE EPIDEMIOLOGY OF FATIGUE: INCIDENCE AND PREVALENCE IN AUSTRALIA.

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Abstract

Three main sources of data provide information about the size and nature of the problem of driver fatigue. First, epidemiological evidence suggests that between 5% and 20% of crashes in Australia are fatigue-related, depending on criteria used for coding involvement of fatigue. Comparison of different groups of drivers indicates that the risk of fatigue involvement for trucks is no greater overall than for cars, despite the vastly longer distances travelled by these drivers. Among trucks, longer combination vehicles seem to be over-represented. Buses, on the other hand, seem to be involved less frequently than other groups in fatigue-related crashes. The involvement of fatigue appears to be considerably more prominent for certain types of crashes, however. The frequency of fatigue involvement is greater in single vehicle accidents, those that occur in remote areas and those that occur at night. Information about the nature and scope of the problem also comes from data collected in survey form concerning the prevalence of driver fatigue. It seems that between 10% and 50% of truck drivers drive while fatigued on a regular basis. The problem seems to be of considerably lesser magnitude for long distance coach drivers, approximately 20% of whom report that driving while fatigued is a regular problem. Commercial drivers who report regularly driving while fatigued are more likely to have been involved in a crash than those who do not. The self-reported use of stay awake pills in the long distance road transport industry varies between 5% and 46%, and seems in part at least to reflect the reported size of the problem. Among the general community, between 4% and 12% of urban drivers report having had a fatigue-related

accident or near accident, with 36% of drivers reporting commencing to drive when fatigued. Finally, the contribution of sleep disorders to the. scope of the driver fatigue problem is being investigated. The data suggest that sleepiness associated with sleep pane affects driving ability and may place people with such disorders at high risk of fatigue-related driver accidents. However, to date, Australian data do not strongly suggest a particular risk of sleep disorders for truck drivers, nor a particular role for sleep disorders in commercial driver fatigue.

In recent years, there has been increasing interest in Australia in driver fatigue as a potentially modifiable risk factor for crashes. While it is well accepted that driver fatigue is a risk factor in road safety, the nature and extent of its role in compromising safety is by no means clear. Considerable effort has been devoted to better defining the role of driver fatigue and the magnitude of the problem in road safety in Australia. Although these efforts have included road safety in general, particular attention has been focused on heavy vehicle safety. The prominence of interest in heavy vehicles reflects both operational reality in Australia, given the distances that need to be covered, as well as pressure from the community for better recognition of public liability issues on the part of the road transport industry.

Current efforts to better understand the nature and scope of driver fatigue in Australia have drawn on three main lines of evidence. Analyses of crash data, and in particular fatal crash data, have dominated study in the area, both for commercial driver fatigue and general road safety. Secondly, direct evidence about the prevalence of driver fatigue have been attempted through surveys. Finally, recent recognition of the potential contribution of sleep disorders to fatigue while driving have resulted in investigation of the prevalence of sleep disorders among potentially high risk groups such as commercial drivers. This paper provides an overview of the data collected in the last 5 to 10 years in Australia documenting the fatigue-crash relationship, the prevalence of fatigue experience and the role of sleep disorders in road safety.

The role of fatigue in crashes

Considerable information has been collected in Australia concerning the role of fatigue in crashes. Evidence from a study of coronial and police reports concerning all fatal crashes in 1988 suggest that, nationally, 5% of all fatal crashes are fatigue-related (Howarth and Rechnitzer, 1993). This figure varied from state to state ranging from 0 to 14%, with the less populated states generally showing higher rates of fatigue-related crashes.

Based on the premise that exposure to long hours of driving is a risk factor for fatigue-related crashes, attention has also been focused on the involvement of trucks in fatigue-related crashes. Analysis of the Federal office of Road Safety (FORS) database of fatal crashes in 1988, 1990 and 1992, revealed that, nationally, fatigue was implicated by the coroner in 5-10% of fatal articulated vehicle crashes, again with considerable variation across states evident (Hartley, Arnold, Penna, Hochstadt, Corry and Feyer, 1996).

Using the coronial and police judgements however, is likely to be an underestimate of the frequency of involvement of fatigue because the definitions used are very narrow. When the NSW Roads and Traffic Authority (1993, 1994) included cases where the description of the crash suggested loss of concentration as well as those cases identified by the police, they reported that 16.9% of all crashes in 1993 and 17.7% of all crashes in 1994 involved fatigue. Western Australian statistics on the other hand, without additional coding beyond police records, reported that 7% of all crashes in each year involved fatigue in 1993 (Hely, 1994) and 1994 (Menhennett, Trent and Maisey, 1995). Thus, one of the major difficulties in comparing analyses of the fatigue-crash relationship lies in the major differences in definition used in studies.

Similar discrepancies can be seen in the evidence estimating the size of the problem for drivers of heavy vehicles. Howarth, Heffernan and Horne (1989) reported that coroners' reports implicated fatigue in 9.1% of Victorian fatal truck crashes between 1984 and 1986. However, when the authors included consideration of factors such as driving hours, comments on tiredness and vehicle movements 19.9% of crashes were found to involve fatigue. Also using an expanded definition, Sweatman, Ogden, Haworth, Vulcan and Pearson (1990) reported that up to 60% of heavy vehicle crashes involved some element of fatigue on the part of the car driver or truck driver.

Studies of the involvement of fatigue in crashes have also attempted to identify particular risk groups and risk factors. Analysis of the involvement of vehicle type has suggested that buses are under-represented in fatigue-related fatal crashes compared with drivers of trucks and cars (Attewell and Dowse, 1992). Drivers of heavy vehicles are not more commonly involved in fatigue-related fatal crashes than car drivers (Howarth et al, 1989; Howarth et al, 1993; Sweatman, Ogden, Haworth, Corben, Rechnitzer, and Diamantopoulou, 1995). This is the case irrespective of the definition used for coding the involvement of fatigue (Howarth et al, 1989). Among heavy vehicles, however, analysis of data from all crashes involving trucks in Western Australia between 1988 and 1992 suggested that road trains are at greater risk than semi-trailers (Ryan and Spittle, 1995).

Analysis of the location of fatigue-related crashes has suggested a higher frequency of such crashes in rural and remote regions. This over-representation of rural areas has been found for fatigue-related crashes involving heavy vehicles (Haworth and Rechnitzer, 1993; Ryan and Spittle, 1995) as well as for crashes involving cars (Attewell and Dowse, 1992). In both rural and urban areas, single vehicle crashes have been found to be over-represented among fatigue-related truck crashes (Ryan and Spittle, 1995) and crashes involving cars (Attewell and Dowse, 1992).

The relationship between crash risk and time of day is well documented (e.g. Haworth et al, 1989; Sweatman et al, 1995; Hartley et al, 1996). The over-representation of the night-time hours in crash statistics is indirect evidence for the involvement of fatigue in these crashes, and very clearly suggests the additional fatigue-related risks posed by these hours. Haworth and Rechnitzer (1993), directly examining the relationship between time of day and fatigue-related crashes, reported a significant difference in the distributions of fatigue-related and other fatal crashes. Relatively more fatigue-related crashes occurred between midnight and 6 am and relatively fewer occurred between noon and 6 pm. Ryan and Spittle (1995) also reported a higher proportion of fatigue-related single vehicle truck crashes overnight, between 6 pm and 6 am.

In summary, then, the epidemiological evidence suggests that between 5% and 20% of crashes in Australia are fatigue-related. From the statistics, buses are under-represented in fatigue-related crashes, with trucks and cars not differing significantly in their level of involvement, although among trucks longer combination vehicles seem to be over-represented. The frequency of involvement of fatigue increases considerably for certain types of crashes, however. Rural and remote zones are over-represented, as are single vehicle crashes, suggesting that risk may be higher when these factors are present.

The prevalence of driver fatigue

Several studies have sought direct evidence about the prevalence of the symptoms of driver fatigue through surveys. A substantial proportion of these have focused on the long distance road transport industry, reflecting in part increasing pressure from the community to improve the safety standards of the industry and in part recognition of the risks posed to truck drivers in Australia by the vast distances that need to be covered.

Williamson and Feyer undertook a national survey of the nature and scope of driver fatigue in the long distance road transport industry in Australia (Feyer, Williamson, Jenkin and Higgins, 1993; Williamson, Feyer, Coumarelos and Jenkins, 1992). The vast majority of truck drivers reported that fatigue was a substantial problem for the industry, with one third reporting it a substantial personal problem (Williamson et al, 1992). Approximately half of drivers in the sample reported experiencing fatigue on their last trip, and indeed on at least half of trips done. The vast majority of drivers reported that their driving was worse when they were fatigued. one third of drivers reported using stay awake pills at least sometimes. The use of stay awake drugs by a substantial minority of drivers was also reported by Hensher, Battellino, Gee and Daniels (1991), who found that 46% of drivers reported taking stay awake pills on at least some of their trips.

Similarly, in a study of Victorian articulated vehicle drivers Howarth et al (1991) found that close to half of drivers reported that they drive on the edge of falling asleep at least sometimes. However, significantly more non-crash involved drivers reported that they never continued to drive when on the edge of falling asleep compared with those who had been involved in a crash in the past two years. Drug taking behaviour did not vary with crash involvement, with approximately one third of drivers again reporting the use of stay awake pills.

In comparison, Feyer et al (1993) found that long distance bus and coach drivers reported fatigue much less often as substantial problem for their industry (about half of drivers) as well as for themselves (about one fifth of drivers), compared with drivers in the freight industry. Relatively few bus and coach drivers reported experiencing fatigue on a regular basis or on the last trip. This difference in the perceived size of the problem is also reflected in very low levels of reported drug use, with only 5% of bus and coach drivers reporting using stay awake pills sometimes. However, like their freight industry colleagues, the vast majority of bus and coach drivers reported that their driving is worse when they are fatigued.

Most recently, Hartley et al (1996) undertook a survey of the nature and scope of the problem for drivers in the freight industry in Western Australia. Part of the rationale for undertaking this study was to specifically examine the impact on driver fatigue of Western Australian conditions. Two important characteristics of Western Australia are particularly relevant to driver fatigue for truck drivers. In Western Australia, the freight industry covers vast distances with a preponderance of remote zone driving. It is also one of two states in Australia which do not regulate driving hours for truck drivers.

About 10% of drivers reported that fatigue is often or always a problem for them, with about one third reporting that it is often or always a problem for the industry. From these data, it seems that fatigue is perceived as less of a problem for the industry in this state than was reported in the national survey by Williamson et al (1992). In fact, far more drivers in the Western Australian sample (35.5%) reported that fatigue was never a problem for them compared with the national sample, where 15.3% of drivers reported that they very rarely experienced fatigue. In line with the problem being reported as being of smaller magnitude, fewer drivers in the Western Australian sample reported taking stay awake pills (16%) compared with the earlier national survey.

Community surveys of driver fatigue in Australia have been relatively rare. Recently, Fell (I995) reported that just over one quarter of a predominantly urban population reported having had a fatigue-related incident, with 4% reporting a fatigue-related accident. Almost two thirds of the incidents were reported as occurring on the open road. Targeting city drivers, Fell and Black (1996) found that 12% of Sydney drivers reported having had a fatigue-related incident. Among those-who reported a fatigue-related incident, approximately one third reported starting the trip fatigued, suggesting that a substantial proportion of drives in the community are prepared to drive when fatigued.

In summary, it seems that between 10% and 50% of truck drivers drive while fatigued on a regular basis. The problem seems to be of considerably lesser magnitude for long distance coach drivers, less than 20% of whom report that driving while fatigued is a regular problem. Commercial drivers who report regularly driving while fatigued are more likely to have been involved in a crash than those who do not. The self-reported use of stay awake pills in the long distance road transport industry varies between 5% and 46%, and seems in part at least to reflect the reported size of the problem. Among the general community, between 4% and 12% of urban drivers report having had a fatigue-related accident or near accident, with approximately one third of drivers reporting that they commenced driving when fatigued.

Sleep disorders and driver fatigue

Recognition of the potential contribution of sleep disorders to fatigue while driving has resulted in investigation of the extent of the role of such phenomena in road safety. In particular, sleep pane has received considerable attention because its major concomitant, excessive daytime sleepiness, clearly has significant implications for driver functioning. A recent study compared the self-reported crash rates of apnoeic, snorers and controls (Bearpark, Fell, Grunstein, Leeder, Berthon-Jones and Sullivan, 1990). The proportion of apnoeic who reported having a crash due to sleepiness was significantly higher than for snorers or controls. Similarly, apnoeic reported pulling off the road due to sleepiness significantly more often than the other two groups. Both the pane group and the snorer group reported falling asleep at traffic lights significantly more often than the control group.

The significance of the symptoms and sequela of snoring and sleep pane for driver fatigue has resulted in investigation of the prevalence of sleep disorders among commercial drivers who are suggested to be in a high risk group for developing the disorder as well as high exposure group (Bearpark et al, l990). Haworth et al (1991) found no difference between crash and non-crash involved articulated vehicle drivers in their response to the Mini Sleep Questionnaire (MSQ). However, drivers involved in a single vehicle crash had somewhat higher MSQ scores than those involved in multiple vehicle crashes. Currently, a major study of commercial driver health is underway, a collaborative effort undertaken by Vicroads and the Road Transport Forum. Three to four thousand drivers nationally are participating in a comprehensive health evaluation, including self-reported sleep problems. Drivers identified by self-report indicators have been referred for assessment at sleep clinics. Preliminary information from this study suggests that the prevalence of sleep disorders among Australian truck drivers is very similar to that described for the Australian population

(Bearpark, Elliot, Grunstein, Cullen, Schneider, Althaus and Sullivan, 1995).

These data suggest that sleepiness associated with sleep pane affects driving ability and may place people with such disorders at high risk of fatigue-related driver accidents. However, to date, Australian data do not strongly suggest a particular risk of sleep disorders for truck drivers commercial driver fatigue.

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3. .FUNDAMENTAL FACTORS

3.1 Time on Task and Vigilance

When a person is driving, he or she has to monitor and respond to various variables that are crucial in completing the driving task. These include, monitoring for pedestrians, monitoring for other vehicles and signs, and monitoring for objects on the road which may impede the progress of the vehicle as well as maintaining vigilance to perform the task of operating the vehicle. This must be completed in conjunction with keeping the vehicle within the boundaries of the road. McDonald (1984) states that it is within this context of the diver's task that we can best interpret the number of studies that require the driver to do vigilant-type activities.

Vigilance studies are based on the classic theory that performance decreases as a function of time on task, which may be due to various factors such as lowered arousal or heightened arousal. The studies on vigilance all share one common feature: they require the subject to respond to a particular stimulus and then record the response. The response may either be in frequency and accuracy of detections or in reaction times. The relationship between arousal and the performance of complex tasks is the focus of much research, with the results of these studies often providing contradictory evidence (Reid 1995, McDonald 1984)

Laboratory experiments have indicated that reaction time increases as time on task increased. Nagatsuka (1996) presented subjects with a choice reaction time task for 120 minutes. The results showed that as time on task increased, the reaction times increased. However, the reaction times were able to be maintained by the implementation of a secondary task.

Similarly, Mascord & Heath (1992) indicated an increase in reaction times between the first period of the task (35min.) and the last period (140 min.) of the task.

Work conducted by Laurell & Lisper (1976) in driving simulators indicated that reaction time increased as a function of time spent on task. More recently Hartley & Arnold (1995) measured the reaction time of drivers who were involved in a three day car rally. The results indicated that by the 3rd day reaction times were slower for drivers than on day one. The slowest reaction times for day three were recorded after the longest driving session for that day. These results were mirrored by a similar decrease in critical fusion frequency results and subjective reports of fatigue and sleepiness.

Stein (1995) examined the accident rate of drivers, the ‘weaving’ behaviour of drivers as well the reaction time of drivers. In regards to the accident data, by day 4 and after the 13^{th} run on the simulator, accident rates increased from 0.15 accidents per run for the first 12 hours to 0.68 accidents per run for hour 18. The standard deviation of lane position measures the drivers weaving behaviour in the lane. It is generally considered that if weaving behaviour exceeds one foot, then there in increase in accident risk. This is due to the increased chances of the driver exceeding the lane edge boundaries. Stein, showed that, as time on task increased so did the weaving behaviour of the drivers, until it reached the critical point (one foot). This deterioration in performance was accompanied by the driver’s decreased ability to maintain constant speeds and an increase of about one third in response times to secondary tasks.

Detection type studies have produced similar results. Naatanen & Summala (1976) conducted a study in which drivers were asked to drive for 257km and detect and name every street sign they saw.

The results indicated that as the drive progressed, detection and reporting of road signs decreased for all drivers, with inexperienced drivers having the highest miss rate. Drory & Shinar (1982) also found similar results, indicating that measures of fatigue were related to the probability of detecting road signs.

Brookhuis, Louwerens & O'Hanlon (1986, cited in Brookhuis & de Waard 1993) using both physiological measures (EEG) and performance measures indicated that after prolonged driving, drivers activation tended to decrease (as measured by a spectral analysis of the EEG) which was found to coincide with decreased performance. This is in keeping with the traditional theory of vigilance and performance.

In contrast, McDonald (1984) cites several papers which do not subscribe to the traditional theory that performance decreases as a function of time on task. In his review of vigilance studies, McDonald states that of the studies which indicated a predicted drop in performance several factors may have contributed to the performance decline. Factors such as driving at night, driving for prolonged periods without rest, and performing vigilance tasks that require high level of concentration, may have had a interactive effect and contributed to the performance decrement observed.

A further indication of fatigue, as a result of time on task, is an increase in accident risk. Hamelin (1987) in his study of lorry drivers indicated that duration of work periods was an important variable in accident risk. Hamelin indicated that accident risk increased substantially after 11 hours of work. This finding supported earlier findings by Brown, Tucker and Simmonds (1970) who indicated that risky manoeuvres increased as a result of time on task.

A report by the Insurance Institute for Highway Safety (1987) indicated that drivers who had driven for more than 8 hours had nearly twice the risk of being in a crash when compared to drivers who had been on the road less than two hours.

Summala & Mikkola (1994) examined the effects of fatigue in fatal accidents by investigating whose responsibility the accident was. The results were divided into two groups, those who had caused the accident (at fault) and those who were involved in the accident but were "not at fault". Of the drivers who were deemed to have been at fault, 20% had been driving for more than 10hours, this was significantly greater when compared to only 8% of drivers who had been driving for 10 hours but were not at fault, indicating that drivers who have driven over 10 hours were more likely to be the cause of an accident.

Although research has generally established that time on task is a causal variable in fatigue, McDonald (1984) concluded that "the relationship between either the reaction time of the vigilance tests..., and the drivers detection, evaluation and response to crucial traffic situations...remains a matter for speculation." (pp 115) is still a valid conclusion given the disparate results reported in much of the literature.

3.2 Time of Day

While research has indicated a relationship between time on task and fatigue, research, into shiftwork and an examination of accident data indicates that time of day impacts on fatigue, with this variable being the more significant mediator.

Research in the past thirty years, has indicated that people are diurnal and that performance and sleepiness responds to a circadian 24 hr clock (Tepas1994). Research has consistently found that an increase in sleepiness and a related decrease in performance occurs at two particular periods of the day, during the night at the time of normal sleep and in the early afternoon. It is during these two periods that human functioning is at its lowest point.

Perhaps the effects of time of day can be most readily seen by the examination of accident data. Research has consistently shown that time of day is an important factor in accidents (McDonald 1984, Haworth, Hefferman & Horne 1989, Haworth & Rechnitzer 1993, Hartley & Arnold 1995, Lisper, Eriksonn, Fagerstrom & Lindholm 1979). Early work by Prokop & Prokop (1955 cited in McDonald 1984) indicated that drivers who had fallen asleep at the wheel tended to do so between the hours of 2300 and 0500 hours (58%) and between the hours of 1200 and 1500 hours.

Horne (1992) examined the characteristics of 58 sleep related traffic accidents. Of these, there were three distinctive time periods that increased the risk of being in an accident. These time periods were midnight to 0200 hours, 0400-0600 hours and 1400-1600 hours. Horne indicated that someone driving between the hours of 4am to 6am was 13 times more likely to be involved in an accident than someone who was driving between the hours of 10am to 8 pm.

Similar findings were reported by Knipling & Wang (1994) who indicated that crashes where drowsiness was a factor peaked during early hours of the morning as compared to “non-drowsiness” crashes which were more evenly distributed throughout the day. Pack, Pack, Rodgman, Cucchiara, Dinges & Schwab (1995) indicated that of the crashes attributed to driver sleepiness, the majority happened between the hours of midnight to 7am and during siesta time around 3pm.

Similarly, Sweatman, Ogden, Haworth, Pearson & Vulcan. (1990) indicated that the majority of articulated vehicle crashes on major Australian roads occurred during the hours of darkness (between 1800 hours to 0600 hours). Ryan and Spittle (1995) found that a higher proportion of single vehicle fatigue related crashes occurred between the hours of 1800 hours to 0600 hours.

3.3 Time on task and Time of Day

McDonald (1984) indicated that the effects of time of day and time on task rarely happen independent of each other and that it would be naive of researchers to think that this would be the case. Shiftwork research is perhaps the best demonstration of the complex interaction that occurs between time of day and time on task.

Rosa & Bonnet (1993) compared an 8 h/5-7 day work schedule to a newly instituted 12 h/ 2-4 day schedule at a gas storage-transmission station. Workers completed a performance and alertness test battery and a questionnaire on sleep patterns. The results indicated that there were decrements in performance and alertness which were attributable to the extra 4 hours work. These decrements were still apparent ten months after the shift change was implemented. The reductions in sleep for the workers across the workweek were most apparent on the night shift. These results supported earlier work by Rosa, Colligan & Lewis (1989) and Rosa (1991, 1995).Rosa (1991) in a 3 year follow up study found persistent decrements in performance and alertness which were attributable to the 12 hours shifts. Duchon, Keran & Smith (1994) indicated that self-report measures showed a consistent manifestation of fatigue for the 12 hour night shifts only. No other effects for the increase in 4 hours schedules were found.

Paley & Tepas (1994) examined the effects of rotating shift schedules on fire-fighters. The authors concluded that workers working on the rotating 8 hour shifts reported lower positive mood scores, higher negative mood scores and greater negative sleepiness ratings on the night shift than those workers on the day shifts.

Tepas & Mahan (1989) provide further support for the interaction between time of day and time on task. Tepas & Mahan indicated that working on the night shift decreased sleep length even in experienced night shift workers. Results from the examination of irregular work schedules in locomotive engineers led Popkin & Tepas (1993) to conclude that irregular shift schedules have a more negative impact on workers with respect to difficulty falling or staying asleep.

Hamelin (1987), examined the effects of time of day and time on task in lorry drivers. Hamelin found that accident risk was low for drivers who had been driving less than 11 hours and driving between the periods of 0800 and 1900 hours. These same drivers showed twice the risk when driving between the hours 2000 and 700 hours. Therefore the drivers with the greatest accident risk were those drivers who had driven more than 11 hours and between the hours of 2000 and 0700 hours.

3.4 Conclusions

- Results from simulator, laboratory and on road research have indicated that time on task is an important causal variable. Generally, as time on task increases so does fatigue.
- Examination of accident data has indicated that there are two distinctive time periods in which accident risk increases, that is in the early hours of the morning (midnight to 0600 hours) and early afternoon (noon to 1500 hours).
- The interactive effects of time on task and time of day have been demonstrated by research into shiftwork. The results consistently showing that an increase in the length of the work period increase the prevalence of fatigue, which is augmented during night shifts.
- If it is accepted that the 24 hours in one day are not interchangeable, then in terms of managing driver fatigue, one must consider both the amount and the time at which one drives.

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4.

ENFORCEMENT

Throughout the developed world, various methods have been derived to counteract the effects of fatigue on the driver. These methods range from the provision of rest areas on the road to the development of in-vehicle monitoring systems. However, the most frequently adopted procedure is the strategy of limiting the hours of driving (Haworth 1995). Research already outlined in this paper indicates that there is some relationship between the number of hours a driver spends behind the wheel and an increase in accident risk. This relationship has been the basic rationale behind the use of driving hour restrictions. Although many countries have adopted a driving hours regime the effectiveness of these regimes is questionable.

What follows is a discussion on how effective driving hour regulations have been in moderating the effects of fatigue, with suggestions as to why these regulations have not been as successful as originally thought. Firstly, however, is a description of the various restrictions used by the different countries.

4.1

Hours of Service Regulations

4.1.1 USA

Hours of Service Regulations as Contained in Part 395 of the Federal Motor Carrier Safety Regulations. (Beilock 1995)

Maximum Driving and On-Duty time.

10 hours driving rule

> After 8 consecutive hours off-duty 10 hours driving is permitted.
>
> After 10 consecutive hours of driving, no driving is permitted prior to an 8 hour off-duty period.

15 hour on duty rule

> Driving is not permitted after 15 hours of on duty time.

60 hour rule

> A maximum of 60 hours driving is permitted during any seven day period. When this limit is reached driving is not permitted until 48 hours have passed.

70 hour rule

> A maximum of 70 hours of driving is permitted during any eight day period. When this limit is reached, driving is not permitted until 48 hours have passed.

4.1.2 Australia

Driving Hour Regulations by State (Moore & Moore 1996)

Currently Western Australia, The Australian Capital Territory, Tasmania and the Northern Territory do not have driving hours legislation.

Maximum Weekly Driving

> NSW and QLD maximum of 12 hours/day

VIC. And SA, none specified but maximum 84

Maximum Daily Driving

NSW, QLD, VIC, SA maximum of 12 hours

Maximum Shift of Continuos Driving

NSW, QLD, VIC, SA maximum of 5 hours

Minimum Shift Rest

NSW, QLD, VIC, SA maximum of 30 minutes

Minimum Continuous Daily Rest

NSW and QLD 6 hours

VIC and SA 5 hours

Minimum Periodic Rest

NSW and QLD minimum of 24 hours in last 7 days

VIC and SA minimum of 24 hours in last 7 days or 2x24 in last 14 days

4.1.3 New Zealand

As of the Transport Act 1962 (Thorne 1996)

No person shall drive a heavy motor vehicle

I) For a continuous period exceeding 5.5 hours
II) For more than 11 hours in any 24 hour period.
III) Work or be on duty for more than 14 hours in any 24 hour period.
IV) Does not have at least 9 consecutive hours of rest in any 24 hour period.
V) Does not have at least 24 consecutive hours off duty after driving for 66 hours or being on duty for 70 hours, which ever occurs first.

Moore & Moore (1996) state that the various Hours of Service Regulations (HSR) throughout the world differ on several variables, including the attributes that are regulated, (working periods, driving periods, the rest periods, etc.) The various regulations also differ on the flexibility that is permitted by the regulations. For example, the Australian HSR have prescribed daily and weekly cycles whereas the USA regulations have greater flexibility.

The other dimensions that HSR differ on is the amount of driving and rest periods required. These differ both on a national and international level. Finally, Moore & Moore (1996) argue that the means of enforcement is a source of difference. In Australia, log books are the primary source of enforcement, whereas in Europe the responsibility is imposed on the operator and tachographs are the primary source of enforcement.

4.2 Effectiveness of Hours of Driving Legislation.

The effectiveness of Hours of Driving Regulations can be demonstrated in two ways. Firstly, by examining the prevalence of drivers who violate the rules and secondly by comparing states who have and who don't have driving hours regulations for fatigue related accidents.

4.2.1 Prevalence of Hours of Service Violations (HSV)

The seminal study on the HSV was conducted by Jones and Stein in 1987. They compared crash-involved drivers and drivers not involved in crashes, travelling along the same road at the same time of day and day of the week. Of the drivers who had been involved in an accident, 22% had logbook violations, indicating they had broken the hours of service regulations.
Ten percent of the comparison sample (drivers not involved in a crash) had logbook violations. A further 2 percent of the accident comparison group had severe logbook violations which would put the drivers out of service under US law.

More recently, Hertz (1991) estimated the prevalence of HSV violations among tractor-trailer drivers. The estimates used the average speed of the drivers to calculate how long they had been on the road. Hertz estimated that at the conservative speed of 40 mph, 90% of drivers were in violation of hours of service regulations (HSR) by more than one hour. This figure dropped to

51% at 50mph, and to 30% at 60mph. The speeds used to determine the percent of HSV were based on the schedules of mangers who set trip speeds at 45-47 mph and on supporting evidence which indicated that drivers average 41mph on a trip.

The propensity for HSV has also been demonstrated by Braver, Preusser, Preusser, Baum, Beilock, Ulmer and Long (1992) and by Beilock (1995). Braver et.al. incorporated the issue of HSV amongst questions of overall pressures faced by drivers. A total of 31% of drivers reported that they exceed the 60 or 70 hour rule. Furthermore, 36% indicated that they exceeded total work hour restrictions. Finally, 6% of drivers stated that they had violated HSR during the previous month.

Beilock (1995) using a similar methodology as Hertz (1991) indicated that HSV is widespread. Assuming an average speed of 55 mph, over a quarter of Beilock's sample must violate HSR or speed limits to maintain schedule. Beilock also reported that one quarter of drivers exceeded 81 hours total work per week and of that, drove for over 64 hours, which is a clear violation of HSR.

A survey of Australian drivers by Williamson, Feyer, Coumarelos, & Jenkins, (1992) indicated that the problem is not limited to the United States. Williamson et.al investigated the percent of drivers who broke work hour regulations on their trips. They indicated that over 50% of all drivers interviewed broke HSR on at least half of their trips, and 30% broke HSR on every trip.

4.2.2 Comparisons

Australia is the ideal place to make comparisons on the effectiveness of HSR, because as noted earlier, some states implement HSR and some states do not. The rationale for comparing states is simple, if HSR regulations have been effective then one would expect to see lower fatigue related accidents and incidents in those states that control hours of service as compared to those that do not.

A recent study conducted by Hartley, Arnold, Penna, Hochstadt, Corry, & Feyer (1996) examined the prevalence of fatigue in the Western Australian transport industry (a non-regulated state) and compared the findings to similar studies carried out on Eastern states drivers who operate under a regulated hours regime. Hartley et al concluded that if WA is compared with states that regulate driving and working hours, there appears to be little difference in the proportion of fatigue related crashes or in the number of hours driven. In terms of fatigue related crashes, Hartley et.al point out that in 1992, Western Australia lies fourth in the number of crashes attributed to fatigue by the coroner. Also, Tasmania, a non-regulated state, recorded no accidents attributable to fatigue within the same time period.

In relation to the number of hours driven, Williamson et al (1992) in their study of regulated states indicated that the percent of drivers exceeding 72 hours per week (maximum under regulated sates) ranges from 25-46% as compared to the Western Australian sample which only found that 30% exceeded 72 hours per week (Hartley et. al. 1996)

These findings led Hartley et al (1996) to conclude that WA drivers were no more likely to exceed weekly driving hours regulations than their Eastern sates counterparts, despite enforcement of driving hours regulations in these states.

4.3 Limitations of HSR

The above evidence indicates that the HSR have had limited impact on reducing fatigue related crashes. The following section deals with some reasons as to why the HSR have been limited in their effectiveness.

There are several reasons as to why prescriptive driving hours have not been as successful as hoped. Firstly, driving long hours has been shown to be one of several major contributors. However, research already outlined in this document has shown that other factors such as time of day interact with the hours driven to impact on fatigue. McDonald (1984) concluded that the effects of prolonged driving are exacerbated by when this driving takes place. Also research has constantly shown that accident risk increases during the early hours of the morning and after lunch. Hence, one limitation of driving hour restrictions is that they do not take into account when the driving occurs. Drivers may drive the prescribed number of hours, but may do so during the most critical driving periods thus increasing accident risk.

A further limitation of driving hour restrictions is that it forces the drivers to work on a shiftwork schedule (McDonald 1981, Haworth, Triggs & Grey 1988). The US 10 hour rule, if adhered to, requires that the driver commence work progressively earlier. This has effectively transferred driving into shiftwork. However, unlike traditional shiftwork where the starting times and finishing times remain constant, the times are constantly changing. This results in an increase in sleep debt and difficulties in circadian adaptation (see other section in this paper) adding to the impact of driver fatigue..

Moore & Moore (1996) state that driving hour regulations have not worked because they have introduced "anomalies". They state that the driving hour legislation fails to take into account factors such as the type of load, the circumstances in which the driver finds himself and also the proximity to the designated destination. The type of load carried by the driver may impact on whether adhering driving hour regulations is feasible for the driver (see Arnold, Hartley, Penna, Hochstadt, Corry & Feyer 1996). The lack of flexibility in driving hour regulations indicates adhering driving hours regulations could be disadvantageous to the driver. This can be clearly seen in an example of where the driver has driven the allocated 12 hours for the day but is only 2 hours away from a destination (home, depot) where they could obtain better quality sleep.

Other reasons put forward as to why HSR regulations have been ineffective include that they limit productivity of companies who obey the HSR (Moore &

Moore 1996), that is, they are economically driven rather than safety driven (McDonald 1984). Furthermore, HSR are seen as unfair because they apply to only certain types of drivers and exclude others (Haworth 1995) such as car and bus drivers who are just as susceptible to the effects of fatigue.

Enforcement of HSR usually takes the form of log books. Anecdotal evidence suggests that this system of enforcement is easy to bypass by simply using two log books, hence drivers see no reason to adhere to HSR. A final limitation of HSR is that they do not take into account individual differences amongst drivers. HSR assume that all drivers are capable of only carrying out a certain amount of work throughout the day, when some of these drivers can carry out more or less than the limits allow.

4.4 Conclusions

- The most frequently adopted procedure for combating fatigue is hours of service regulations. These regulations differ on what is limited, how it is enforced, the flexibility and the actual amount of driving permitted (Moore & Moore 1996).
- Research outlining the prevalence of HSV has indicated that most drivers do not adhere to the rules. Also, research comparing the states which impose restrictions and those that do not, indicate that HSR have not substantially reduced the problem.
- Several reasons have been outlined as to why HSR have not been effective in limiting fatigue, these include, a) the introduction of "anomalies", b) effects on productivity, c) lack of flexibility, d) the importance of other factors in fatigue.
- The number of HSR violations indicate that other means of enforcement must be found. These include the introduction of curfews or the use of in-vehicle monitoring systems. The latter of the two has received the most attention and is perhaps the method of preference.

4.5

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5.

ENGINEERING SOLUTIONS/IVHS

5.1 Introduction

Intelligent Vehicle Highway Systems (IVHS) are an emerging technology in road safety. IVHS is the integration of technologies (sensors, control and communication) to existing and projected vehicle and road structures to maximise the efficiency of the transportation systems (Hancock and Parasuraman 1992). IVHS technology ranges from the use of intelligent intersection control such as SCATS to the in-vehicle use of electronic road maps for navigation (Hancock & Parasuraman 1992)

The general aim of IVHS is to enhance the safety and efficiency of current transportation systems (Hancock 1994) and in doing so address a major safety issue throughout the world that of driver fatigue. A considerable amount of research has gone into developing IVHS to combat fatigue. The majority of this research is aimed at developing on-board driver monitoring systems or accident prevention systems. As such, the following discussion will focus on IVHS as it relates to the on-board monitoring of drivers.

5.2 Rationale for Using IVHS

Technological advances are being made in developing IVHS to counter the fatigue safety problem. Several researchers have argued that IVHS is the emerging method to combat fatigue. Brown (1996) argues (albeit pessimistically) that there should be continued development of IVHS in light of the fact that other countermeasures such as training, education and legislation of driving hours have only had limited impact in reducing fatigue related accidents.

This is evidenced by the fact that the NHTSA General Estimates System, attributes 56000 accidents per year to drowsiness or fatigue(Freund, Knipling, Landsburg, Simmons, & Thomas 1995). This is considered by the authors as a conservative estimate. Knipling & Wang (1995) revised estimates of the problem of drowsy drivers in the USA and they concluded that drowsiness or fatigue was a causal factor in 1.2 to 1.6% of all accidents reported to the police. Driver inattention due to fatigue was seen as a more frequent occurrence. Similarly, Maycock (1995) in the UK noted that car drivers indicated tiredness is a contributing factor in 10% of their accidents. The numbers are similar for Western Australia, with the Select Committee on Road Safety (1996) reporting that 16% of fatal crashes in country areas had no discernible cause other than fatigue. Given that some accidents involving fatigue go unreported all these figures can be considered underestimates.

Knipling, Wang & Kanianthra (1996) indicated that the feasibility of using IVHS programs to combat fatigue was demonstrated by research evidence which suggests that:

> "Drowsiness can be detected with impressive accuracy using driving performance measures such as fluctuations in vehicle lateral lane position and drift & jerk steering.
>
> The use of direct unobtrusive driver psychophysiological monitoring (eye closure) could potentially enhance drowsiness detection significantly.
>
> Incipient drowsiness/fatigue is generally measurable well before the occurrence of episodes of involuntary sleep. The opportunity exists to intervene to advise/alert the driver several minutes or more before he or she "drops off".
> (Knipling, Wang & Kanianthra, 1996, pp. 2)

5.3 Issues in IVHS R & D

Taking these factors into consideration it is obvious that IVHS is a feasible countermeasures program. However, there are several issues which confront

IVHS systems and their applicability and adaptability to combating fatigue. The following section will address some of these issues.

5.3.1 Cost

The acceptability of the IVHS as a countermeasure program will rely heavily on its cost. Brown (1996) indicated that the benefits of IVHS must outweigh the cost of the system. If the perceived benefits do not outweigh the cost then IVHS will not be accepted as standard instrumentation. Brown also argues that the cost of the system must not be greater than that of a reasonably good quality sound system (Aus$200-300), that is it must be comparable to a wanted car component. However, at the moment this does not appear feasible. As Knipling & Wierwille (1994) indicate, equipment such as lateral lane position monitors and psychophysiological measurement devices will inflate the cost of such systems.

Haworth (1996) argues that the benefits of IVHS are likely to be greater in trucks, particularly articulated trucks than in cars. Haworth notes that the proportionate cost of an IVHS is far less for truck owners than for car owners. That is, the purchase price of an articulated truck is 10 times that of car, therefore IVHS represents a far smaller proportion of the purchase cost for truck drivers.

5.3.2 Driver Workload

The question of driver workload is the primary issue facing ergonomists. Simply, workload is defined as the demand a task imposes on the operators limited resources. The workload imposed on the operator is influenced by factors such as the person capabilities, motivation and operator mood (de Waard 1996). There are several issues which arise concerning driver workload and IVHS. The first of these is that of increased information to the driver. Hancock & Parasuraman (1992) expect that there will be an increase in information to the driver, from the additional instrumentation in IVHS. This increase in information presented to the driver may interfere with the drivers task. Thus Paley & Tepas (1994) hypothesised that such an increase in instrumentation and displays may lead to driver overload.

The second issue of concern is that of automation. Ideally, to completely eliminate the problem of fatigue, the system would be completely automated and the driver would be reduced to a systems monitor. However, Hancock & Parasuraman (1992) indicate that several studies on automated systems have revealed a rather complex relationship between the level of automation and operator workload. The research into flight systems (Wickens 1992), has indicated that increased automation of systems may actually result in increased driver workload which is associated with monitoring of the system.

Other relevant research has indicated that humans are poor systems monitors and an increase in enforced vigilance will result in greater workload and increase fatigue. Tepas & Paley (1992) argue that the lengthy monitoring of IVHS may have the effect of putting drivers to sleep.

Also Tepas and Paley indicate that if the automated system is not perceived as being accurate then driver workload will increase because the driver will have to devote more attention to what is perceived as an unreliable system (the issue of system accuracy will be discussed in a later section).

Hancock and colleagues (Hancock & Parasuraman 1992, Hancock, Dewing & Parasuraman, 1993) indicate that IVHS technology must take into account the issues of driver workload. In dealing with the influx of driver information, Hancock and colleagues argue that the instrumentation displays within the cab should be “operationally critical”, that is critical to the safe operation of the vehicle. In terms of the degree of automation, they propose that instead of IVHS technology reducing the level of driver workload,(which may be problematic in itself), it should optimise driver workload.

5.3.3   Low False Alarm Rate

The accuracy of IVHS systems is being addressed by examining traditional signal detection theory. In this instance a false alarm refers to the automated system indicating that the driver is fatigued when in fact the driver is not. Inherent in this theory is that the problem of false alarms increases with low frequency events, such as driver drowsiness. Wierwille, Wreggit & Knipling (1994) argue that if a system had a 1% false alarm rate, and the driver was drowsy 1% of the time, the number of false alarms equals the number of hits. Similarly, if false alarms are produced one percent of the time and the driver is drowsy only 0.1% of the time, then the ratio of false alarms to hits is 10:1, ten times the amount of incorrect information. It is important to resolve this issue because, if the driver perceives the system to be inaccurate, it will increase the workload of driver, or the driver may simply switch the unit off.

Progress in eliminating the false alarm rate is being made by examining the algorithms which the systems will use. Knipling & Wierwille (1994), and Wierwille, Wreggit & Knipling,(1994) indicate that a multiple number of sensors (performance, psychophysiological) will need to be used with strict criteria for identifying when the driver is indeed fatigued. Several authors (eg .Haworth 1992) have suggested that a decrease in false alarms could be gained by having a two step process in which there is initial collection of driver data by an unobtrusive vehicle measure followed by a verbal task. If a threshold is reached in both of these measures than the system will intervene, if however, a threshold is not reached then the system will revert back to monitoring the driver.

5.3.4 Unobtrusiveness

If IVHS are to be accepted then they must be unobtrusive. The goal of IVHS is to measure the status of the driver without the driver doing anything other than drive (Wierwille, Wreggit & Knipling 1994). Haworth (1992) argues that the degree of obtrusiveness depends on the degree to which the driver is aware of the system and the amount of interference with the driving task. Furthermore the system must not antagonise the driver and must not interfere with the driver’s ability to drive the vehicle. Hence the measures that are adopted must not interfere with the driving tasks. But by the same token they must not be overly hidden as to be viewed as “spy in the cab” devices (Brown 1996)

5.3.5 Individual Drivers

Any mass produced in-vehicle detection system must be able to detect any deterioration in the driver’s performance whilst taking into account individual differences. Haworth (1992) indicates that a system such as that developed by the Renault Motor Company would be a feasible outcome.
The Renault warning system takes a baseline measure of the driver’s performance during the initial stages of driving. The subsequent performance of the driver is then compared against the initial baseline measure.

Similarly, Onken & Feraric (1996) propose a driver monitoring system called Driver Assisting System (DAISY) in which a model of the driver performance is obtained in the initial stage of driving. The system then has a model with which to compare the drivers future performance.

5.3.6 Other Issues

There are several other issues which the IVHS community must contend with. Hancock (1994) argues that although a perfect system may be developed, it still needs to gain the acceptance of the wider community. Hancock argues that it is possible that the people who are most at risk, young males, are also likely to be the ones who take least advantage of such a system. Brown (1996) also contends that if the general population does not see the benefits of such a system then regulatory bodies will be reluctant to legislate for the use of these systems despite the obvious advantages in detecting and alerting drivers of their fatigue.

A contrary problem is that drivers would come to depend on the system. Haworth (1992) raises the question that some drivers will use these monitors to keep them awake or to extend long distance driving performance until the system tells them they are fatigued. This raises the issue of whether the system should take full control and make the driver stop (perhaps reducing its acceptability) or wether the decision to stop should be left up to the driver.

A further issue, is that of legal liability. If the system fails and the driver is involved in an accident in which fatigue is said to be the cause, then this may give rise to legal implications. To date the issue of legal responsibility concerning IVHS has not been addressed. This has to be resolved before any consideration can be given to implementing IVHS systems.

5.4 Future Prospects

Despite the several issues that are still to be resolved, the future for IVHS programs looks promising. Much research is currently being conducted by organisations such as the NHTSA in developing driver warning systems. The establishment of IVHS America, a government funded body, ensures that research in this area will continue (Hensing 1991). These two organisations form the core of an ad hoc national program in America called Mobility 2000 which is devoted to the enhancement of road safety through the use of IVHS (Hensing 1991).

There is also ongoing research within the European community. The DRIVE program (Dedicated Road Infrastructure for Vehicle safety in Europe) is not only concerning itself with on-board monitoring of the driver but with other aspects of the road environment. The DRIVE program's main aim is to transform the European road environment into one in which the individual drivers are better informed and monitored, and where there is cooperation and communication between "intelligent" vehicles and road users (De Waard & Brookhuis 1991).

The establishment of ITS Australia and the involvement of car manufacturers such as Renault, Nissan and Toyota will further meet the research needs in this area.

ITS Australia is concerning itself with the promotion of new technologies to improve the safety of Australian roads and is examining factors such as Advanced Vehicle Control Systems (AVCS) and Advanced Traffic Management Systems (ATMS). However, the remote zone driving environment of Australia raises special challenges. Whereas in-vehicle fatigue monitoring will be of great value to remote zone driving, road based IVHS are probably not cost effective due to Australia's vast remote zones network of infrequently travelled roads.

Although, the majority of projects are yet to be completed, both in Australia and overseas, the prospects for the future are promising.

5.5 Conclusions

- Fatigue is a dimension ranging from declining performance on vigilance tasks (inattention), through to outright falling asleep. If IVHS is going to be effective than it needs to deal with all these states.

- Research has shown that IVHS are a viable method of combating fatigue.

- The effectiveness of IVHS in combating fatigue, depends on how efficiently and how promptly the issues such as those presented in the paper are resolved.

- The future of IVHS looks promising, with many countries establishing ITS initiatives .

5.6

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6. SLEEP FACTORS

6.1 Introduction

Sleep and sleepiness are among the most basic of human behaviours and as such we spend a significant proportion of our lives sleeping. For most individuals this includes an extended period of sleep, for a period of eight hours, at least once a day. Humans are diurnal animals and therefore this main period of sleep occurs during natural periods of environmental darkness. Disruption in normal sleep patterns can be caused by abnormal pathology including such things as narcolepsy and obstructive sleep apnoea (OSA). Mismanagement and abuse of the work rest schedule can also cause disruptions to normal sleep, producing excessive daytime sleepiness (EDS) and chronic sleep debt. (Diagnostic Classification Steering Committee, Thorpy & Chairman, 1990; Kryger, Roth & Dement, 1994).

Mitler (1996) argues that there is a continuing tendency for society to place less emphasis on obtaining adequate sleep. Societies failure to understand the effect of inadequate sleep on the entire 24 hour cycle combined with modern transportation and industrialisation have created major public safety problems. Even modest amounts of daily sleep loss accumulate as a sleep debt, manifesting as an increasing tendency for the individual to fall asleep. When sleep deprivation is present, physical activity is minimal and circadian reinforcement of sleep is maximal, the likelihood of a lapse in vigilance becomes high. In every work environment where sustained attention is necessary for safety, research has shown that the probability of an accident rises and falls along with the biological tendency to fall asleep (Mitler, 1996; Tepas and Mahan, 1989).

6.2 Factors impacting on driving

On any particular journey, a driver may suffer from the effects of fatigue or sleepiness for a number of reasons; some associated with the task of driving, others to do with health or general lifestyle factors. Among the former would be the length of time the driver has been driving. Many business and commercial drivers work prolonged and irregular hours and drive long distances every day. These factors may be compounded when a driver is driving at times when his/her circadian rhythms are out of step with the physical demands being placed on him/her by the driving task thus causing excessive sleepiness.

Further drivers may experience episodes of excessive sleepiness because they have had insufficient sleep before commencing a journey. Indeed the effect of sleep deprivation may be cumulative, dependent on sleep patterns occurring over a significant period of time prior to the journey. Combined with these work and lifestyle practices there is an increasing awareness of medical conditions which contribute to causes of excessive daytime sleepiness, such as sleep apnoea, and narcolepsy (Maycock, 1995). The following sections will look at the effects of these factors on driving and describe their relationship to crash statistics.

6.2.1 Work Schedules

Tepas and Mahan (1989) argue that many fairly common work schedules interact antagonistically with sleep, particularly those shifts which include some degree of night time work. Early research and theory on the effects of attempting to sleep at other than habitual sleep times, suggest that night shift workers have a tendency to suffer from an insomnia-like sleep disorder, consequently individuals have difficulty falling and staying asleep.

However, Tepas and Mahan indicate that more comprehensive research of experienced night shift workers has provided a different view of the sleep work relationship. Ordinarily, individuals make a choice as to what time they will sleep. Most individuals who work throughout daylight hours elect to take their main sleep period just before going to work. On the other hand, most night shift workers elect to take their main sleep period just after finishing work. Thus, there is not only a variation in the order in which different shift workers sleep but also the time of day at which they sleep (Tepas, 1982b). Furthermore extensive research by Rosa and Colligan (1989) and Rosa (1991) has identified that night time workers actually have a reduction in total sleep time. Therefore establishing that these individuals are susceptible to suffer from chronic sleep debt (Walsh et al., 1981; Tilley et al., 1982 cited in Tepas & Mahan, 1989).

6.2.2 Narcolepsy

There are many diseases associated with abnormal sleeping and waking. One of the most common is narcolepsy. Narcolepsy is a dysfunction involving the central nervous system and bouts are characterised by immediate Rapid Eye Movement (REM) sleep where non-REM sleep would be expected. That is, the sufferer may experience sudden sleep attacks, hypnagogic hallucinations and/or paralysis on wakening or falling asleep (Mitler, Nelson and Hajdukovic, 1987). This disorder may have potentially catastrophic consequences both for the sufferer when driving and other road users. Narcolepsy appears to be hereditary, and most suffers are well aware of their condition by adulthood (Bendel,1995).

Parkes (1994) indicates the population prevalence of narcolepsy is estimated as 0.004 with perhaps 20,000 cases in the U.K. and 26,000 reported cases in the U.S. Preliminary research in Australia would suggest that population prevalence of this disorder is similar to that reported elsewhere throughout the world (Bearpark, Ellition, Grunstein, Cullen, Schneider, Althaus and Sullivan,1995).

6.2.3 Obstructive sleep apnoea

Obstructive sleep aponea is characterised by repetitive episodes of partial or complete obstruction of the upper airway (throat) during sleep. These episodes are the result of sleep related loss of muscle tone in an already narrow floppy throat. Predisposing factors include anatomical obstructions (such as enlarged tonsils and adenoids), increasing age and obesity. Loud snoring is a usual accompaniment, also reflecting throat narrowness and floppiness. Each obstructive episode is terminated by arousal which is usually momentary. In more severe cases hundreds of such episodes can occur per night, with attendant marked disruption of sleep. The most obvious consequence of this to the patient is daytime sleepiness (Farrell and Barnes, 1996).

Snoring is extremely common and it is known that only a minority of heavy snorers have OSA. Gibson (1994) argues however that this minority amounts to quite a substantial number of individuals. Numerous studies have indicated that the condition of obstructive sleep apnoea affects up to 5% of the total population. While this research indicates that prevalence of OSA is distributed throughout the age groups, the highest incidence is in males over 40 years of age, where 20% may be affected to some degree. Predisposing lifestyle factors are obesity and alcohol consumption.

The overriding effect of OSA is sleepiness and actually falling asleep and obviously this has major implications for social and family life, for work and particularly for driving. Road accidents are common amongst sleep apnoea individuals and this occurs particularly in monotonous situations such as motorway driving.

Epidemiological studies of accident proneness of OSA sufferers over the last 20 years throughout the world have indicated the incidence of OSA is up to 5% of the total population.

6.2.4 Excessive Daytime Sleepiness

Excessive daytime sleepiness (EDS) results from disturbance of the sleep pattern, including the reduction of time spent in rapid eye movement (REM) sleep. As a result the individual may have a natural inclination to sleep during the daytime. Farrell and Barnes, (1996) argue that this condition has obvious implications in any situation where mental concentration is required, such as driving a vehicle. For example when the disease reaches a severe stage, lack of sleep can cause the sufferer to drop off while waiting for traffic lights to change.

6.3 Impact on driving

An alert and vigilant state is necessary to operate a vehicle safely. The ability to maintain an alert and vigilant state is directly and causally related to the quantity and quality of prior sleep. For each individual there is an optimal amount of sleep which maintains an optimal prolonged period of alertness. Furthermore, optimal sleep and wakefulness are organised within the constraints of a circadian rhythmicity.

Any disturbance of either state directly, or of their circadian organisation, increases one's level of physiological sleepiness. A reduction in motivation or alerting stimuli then serves to unmask the physiological sleepiness (Roth and Roethers, 1988).

6.4 Sleep and accidents

The act of falling asleep at an inopportune time, regardless of the reason, has and will continue to wreak havoc on industrialised societies. Mitler (1989) states that the probability of falling asleep at the wheel is dependent on numerous factors including those relating to the individual characteristics of the driver, the amount of driving undertaken, the time of day the driving is being undertaken and the impact of previous work/driving on this driving episode. Research indicates that operator fatigue and/or inattention appears to be second only to alcohol as the most common cause of all vehicle crashes (Mitler, 1985; Mitler, 1989).

Although the identification of sleep related accidents is problematic, the evidence from 'in depth" studies, suggests that sleep may be a factor in between 10 and 25 per cent of accidents, the actual proportion depending on a range of factors including type of road, time of day and severity of accident.

Numerous studies of the Transportation industry have provided evidence showing that traffic accidents peak in accordance with peaks in human sleep tendency, that is during the early hours of the morning and mid afternoon (Mitler, 1996; Folkard, 1981; Maycock 1995; Akerstedt, Czeisler, Dines & Horne, 1994; Horne & Reyner, 1995). Of these accidents it has been reported that up to 15% are caused by drivers falling asleep. In a Texan study by Langlois (1984) it was found that drivers over 46 years of age were more likely to be affected by the afternoon peak than other drivers (cited in Horne, 1992).

Horne (1992) in a study in collaboration with the Leicester police found that individuals driving between the hours of 4am and 6am were 13 times more likely to have a sleep related accident than someone driving during any other two hour period. In addition Maycock (1995) found that tiredness-related accident involvements as a proportion of all involvements, are greatest in the early hours of the morning (27% between 12mn and 0400 - corresponding to 36% of accidents) falling to minimum of 3% (4% of accidents) in the morning hours (0800 - 12md) and rising thereafter through the afternoon and evening periods.

Knipling (cited in Graham, 1995) estimated that fatigue's role in truck crashes probably is not higher that 20% and may be less than 10%. A 1992 study by the Insurance Institute for Highway Safety found that nearly one fifth of the 1,247 drivers interviewed reported having fallen asleep at the wheel (Graham, 1995).

Many traffic safety and clinical sleep experts believe inattention, which is more likely to occur in the sleep deprived, may play a role in about one million crashes annually, that is one sixth of all crash in America. Recently a British survey of male drivers reported that 7-10% of all crashes were attributed to 'tiredness' (1996 Drive Alert...Arrive Alive State Campaign Plan)

Maycock (1995) found that tiredness as a contributory factor in accident involvements differed significantly on three types of roads: on motorways 15% of involvements were tiredness related, on rural roads the proportion was 10% and on built-up roads 5%. Australian studies have found that the reporting of serious accidents in rural areas are proportionally higher than those reported in urban areas mainly due to fatigue or sleep factors (Summers & Hartley, 1996).

Horne and Reyner (1996) argue that sleepiness accounts for a significant number of accidents on monotonous roads. These accidents usually occur during the early morning and early afternoon . They suggest that drivers are always aware of sleepiness prior to a driving incident, stating that it is not possible to 'fall asleep at the wheel' without knowing one was sleepy, although the subjective forewarning of sleepiness prior to an incident could be short.

Tiredness as a factor in accidents also differed significantly between the age groups with older drivers being less likely to be involved in these accidents. This is probably due to the fact that older drivers drive fewer miles and are less likely to be driving when tired or at inappropriate times of the day (Maycock, 1995).

6.5 Counter measures to sleepiness

If a driver becomes aware of feeling sleepy, he/she may take measures to counter the effects. In a recent study of transport industry drivers in Western Australia respondents who reported nodding off whilst driving were those drivers who worked long hours on fixed schedules and therefore had little flexibility in managing their sleepiness. Often these schedules precluded those drivers from obtaining adequate sleep prior to their journey and due to the nature of their work schedules they were unable to rest when they felt they needed to. Data indicated that these drivers were more likely to be involved in accidents in the preceding 12 months. Drivers who had flexibility over their driving schedule reported the most effective countermeasure to sleepiness was to take a break from driving period (Arnold, Hartley, Penna, Hochstadt, Corry and Feyer 1996).

In a U.K. study of both HGV and car drivers Maycock (1995) found that drivers identified several measures to counter the effects of sleepiness whilst driving these included: getting some fresh air, taking a break and listening to the radio. Whilst taking a break from driving is often advocated for the sleepy driver, little research has been undertaken on the efficacy of such breaks and what they should entail.

Naitoh (1992) argued that daytime sleepiness is best overcome by sleep, with 4 minutes being the minimum for some recuperation. Unaccustomed naps beyond 20 minutes lead to unwanted sleep inertia or grogginess (Naitoh, 1992) hence, 15 minutes seems to be optimum (Gillberg, Kecklund, Axelsson & Akerstedt, 1994; Naitoh, 1992). However, Nillson, Nelson and Carlson (1996) suggest that such naps may alleviate only some of the effects of lack of sleep.

Drory (1985) found that a 30 minute nap half way through a 7 hour simulated drive did reduce subjective feelings of fatigue in the driver but did not affect their performance on the driving task. Further Chan, Phoon, Gan and Ngui (1989) found that such intermittent naps throughout periods of vigilance reduced the quality of the sleep subjects obtained during the regular sleeping period. Maycock argues, therefore that it is clearly necessary to determine as objectively as possible, the relative effectiveness of alternative potential countermeasures.

It seems likely that the probability of falling asleep at the wheel will depend on a number of factors including those relating to the individual characteristics of the driver and to the amount of driving undertaken. These factors need therefore to be taken into account in future research and in the development and implementation of any Fatigue Management Programs

6.6 Conclusions

- Disruption in normal sleep patterns can be caused by narcolepsy and obstructive sleep apnoea (OSA), mismanagement and abuse of the work rest schedule. This can cause disruptions to normal sleep, producing excessive daytime sleepiness (EDS) and chronic sleep debt

- These factors also impact on driving, with research indicating that these conditions are a causal factor in a large proportion of accidents attributed to fatigue.

- Males over the age of 40 that are obese and consume alcohol were identified as the main risk group. Countermeasures such as taking 15 naps have been shown to be effective in minimising the effects of sleep factors.

- The emergence of medical factors as a cause of fatigue indicates a necessity for more research and cooperation with medical practitioners and sleep specialists.

6.7

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7.

EDUCATION FACTORS

7.1 Education and Publicity

Tepas (1993) proposes that there is a need to differentiate between disseminating information and providing education in any discussion of the usefulness of each technique. He argues that information can be defined as the "communication of news, knowledge and facts" and education as "instruction or training whereby information is developed, learned and used (p200).

There is an assumption when providing information, that all users require similar information and that this information will be promptly assimilated and used. However little research has been conducted to evaluate the usefulness of distributing such information and just how effective the spread of fatigue related information has been in reducing mortality and morbidity associated with fatigue related crashes.

Haworth (1996) argues that educational programmes have traditionally been most successful at informing people and least successful in changing behaviour unless they have been undertaken in support of an enforcement programme (eg. Cameron, Haworth, Oxley, Newstead and Le, 1993)

In providing education programmes there is an assumption that long-term changes in behaviour will ensue. Given this assumption the design of an efficient programme for the education of workers within the transport industry on fatigue presents difficulties and by its very nature will be time consuming. Tepas (1993) suggests several principals that may guide the development of educational programmes on fatigue.

7.1.1 Principles for Effective Education Programs

Fatigue Educational Programme (FEP) recommendations must be relevant to the specific group(s) and work system(s) they are aimed at. Haworth (1996) notes that truck drivers are often subject to greater incentives to continue driving than car drivers, and that this is particularly pertinent to those who journey over long distances. Therefore in order to maximise the effectiveness of FEP's, the programme needs to address and acknowledge the broader social framework within which it is to be implemented.

There is an inherent need for recommendations within fatigue education programmes to be both practical and socially acceptable to the specific group and work system they are aimed at. The recommendation of behaviours that workers may perceive as impractical may lead to the rejection or workers ignoring the entire educational effort. For example, given the nature of many long-distance truck drivers work schedules they find themselves somewhat separated from their social groups and culture. It is therefore important that recommendations from fatigue education do not further separate these individuals.

Table 1 outlines some of the education programs aimed at the driving population in Australia to inform on the impact of fatigue on driving performance. As can be seen from this table much of the information provided to workers is aimed at what occurs as a result of fatigue and as such is not driver specific information.

Table 1. Some educational measures undertaken in Australia

ORGANISATION	TYPE OF MEASURE	THEME

RESPONSIBLE		
Transport Accident Commission	television advertisements radio press billboards	“Concentrate or Kill” “Wake up to yourself” “Fatigue Kills”
Vic Roads	sign posts approaching rest stops	Various
Vic Roads	sign post approaching rest stops	“Drowsy drivers die
Vic Roads	brochure	“Safety hints for country drivers”
Vic Roads	brochures, posters	“Snoring. It’s no joke”
Federal Office of Road Safety	country television, stickers	“Crash in bed instead”
Federal Office of Road Safety	radio	
Roads and Traffic Authority of NSW	brochures	“Stop. Revive. Survive.”
Queensland Transport	brochures	“Stop. Revive. Survive.”
National Road Transport Commission	Fatigue Management Training Course	

Adapted from Haworth (1996)

Tepas (1993) argues that educational programme recommendations must also be limited in number if they are to be remembered and used. It seems obvious that too many recommendations can be made thus decreasing the likelihood that these recommendations will be assimilated into current work practices. Tepas (1993) states that ideal number of recommendations to adopt should be around seven plus or minus two, based in part on his own teaching experiences and on Miller’s classic estimation of the limits of human capacity for processing information (Miller, 1956; Tepas, 1993).

Such educational or training programmes require a high level of motivation and significant investment of workers' time. There is strong argument for designing programmes with the input of workers so that they are presented in a way that workers will find readily applicable and efficient. Prospective drivers have a distinct training advantage, they are not burdened by flawed fatigue coping strategies that have been established in the past by a programme of self-instruction. Therefore there is strong suggestion for the efficacy of pre-driving fatigue education programmes directed at school aged children.

Carlson (1991) in a controlled educational programme for shiftworkers identified a positive behaviour change following six weekly , one hour interactive sessions. Thus suggesting that tailored training may have an impact. However, it has been argued that there is limited positive evaluation from any educational programmes alone that show long-term changes in the personal habits of adult workers.

It should established that fatigue educational programmes alone are not a substitute for needed improvements in work scheduling practices. Following the Second International Conference on Fatigue in Transport held in Western Australia in February 1996 it was noted that the development and implementation of any fatigue management program should be couched within an occupational health and safety framework. A prudent approach suggests that fatigue educational programmes should only be practiced when they supplement an on-going work schedule evaluation of the same workers and management. Therefore such programs need to focus on changing the culture of the organisation towards fatigue rather than just focusing on driver's work schedules. The main benefit from occupational health and safety programs is to improve the safety climate at all levels in an organisation, with benefits flowing through all companies' operations.

Tepas(1993) notes that the actual impact of a specific fatigue educational programme cannot be predicted, and evaluation is therefore imperative. Such evaluations need to include comprehensive audits of records of all incidents that result in any interruption to work. This information can then be used to target specific education at these unsafe practices and hence assist in preventing future fatigue related incidents. In the US the FHWA found that keeping records of accidents and their use to take disciplinary or educational measures is effective in reducing crashes (Freund, 1993).

Haworth (1996) reports that within Australia those programmes that provide information that support enforcement programmes have led to reductions in casualty crashes. Examples of such programmes are those that provide education on the hazards of drink driving and which have strong enforcement support. These have been shown to very successfully reduce crashes due to these factors.

Conversely, for advertising programmes aimed at young drivers where no enforcement is associated, no reliable evidence has shown reductions in the risk of serious casualty crashes involving the target group. Therefore to date, within Australia, it appears that fatigue related programmes have been most successful in eliciting change when they support enforcement programmes. However, Haworth (1996) notes that the benefit of increasing public awareness of fatigue as a road safety issue may make future legislative or technological measure which will be effective in reducing fatigue-related crashes more acceptable to the road user.

7.2 Driver Training and Progressive Licensing

Driver training has often been suggested as one of the most effective strategies to minimise the effects of driver fatigue through a decrease in fatigue related crashes. However, it has been argued that the benefits of establishing and enforcing driver training through legislative changes such as compulsory driver training prior to licensing and the graduation of licenses, must be balanced against the cost of regulation, such as possible reduced operating efficiencies. This is particularly pertinent to much of the transport industry (Mahon,1996). It has been argued that to achieve success through driver education in managing fatigue both government and industry must work in partnership and that all driver training must be pertinent to different driving groups.

The Queensland government in conjunction with the Queensland Department of Transport have initiated as part of a training programme for industry workers the Fatigue Management Program. This program targets both industry, operator and management. It has achieved this through targeting the development and implementation of training schedules and education programs that focus on fatigue. These programmes outline the need for drivers to acquire appropriate amounts of sleep, develop strategies for avoiding sleep loss and consider the behavioural and physiological consequences of tiredness. It is estimated that up to 20% of the Queensland Transport fleet will take up the Fatigue Management Program over the next few years (Mahon, 1996).

A report of the W.A. Select committee on Road Safety proposed that driver training programmes are required for many groups of drivers, in particular the young driver, the increasing population of older drivers and long distance drivers. The report emphasises that the focus of driver training for novice drivers is to provide them with as much experience as possible, thus improving these driver's perception of potential hazards. Driving simulators or simulated cars may prove to be a useful and cost effective method of training for this group (Stoner 1995, Smith & Hartley 1996).

Graduated Driver Licensing systems have been recommended in many countries through out the world. Ontario in Canada has implemented a graduated licensing system that limits first year drivers in the number of passengers they can carry, limits on speed, zero Blood Alcohol Concentration (BAC) for the novice driver and BAC not exceeding 0.05% for the accompanying driver. The accompanying driver must also have had their drivers license for a period of not less than four years and the novice driver is restricted from driving during the hours of midnight and 5am. While these restrictions are limited for second year drivers, a full license is not granted prior to passing an advanced drivers course and displaying two years of penalty-free driving.

The Western Australian government has received a recommendation recently outlining a curfew on young drivers. This is as a result of increasingly consistent evidence that there is an increased probability that young (often male) drivers are more likely to be involved in crashes during night-time hours than are their older more experienced counterparts (Select Committee on Road Safety, 1995). In Sweden, licensing bodies have legislated such that novice drivers are not awarded a full licence until they have completed 3,000kms of driving experience (Langley, Wagoner, Beg, 1996).

However the WA Select Committee on Road Safety Report (1996) describes some consideration prior to implementing graduated licensing programmes. These include the fact that graduating systems may in fact preclude those drivers who most need the practice in 'real' traffic situations from gaining this experience due to the nature of their restrictions. Further that such graduated licensing systems address the need for driver training in only one group of drivers and therefore misses other groups such as the older driver. The majority of these programs have only recently been implemented, hence, the results on the effectiveness of these programs is still some time away.

7.3

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8. ROAD BASED FACTORS AND COUNTERMEASURES

Other sections of the full report have looked at a range of variables in fatigue related crashes and possible countermeasures. This section examines road based factors which appear related to fatigue crashes, and road based countermeasures which have been identified as useful in preventing fatigue related crashes. To put the approach into perspective the section commences with a brief review of epidemiological studies of the causes of crashes and draws attention to the role of impaired attention to the road in crash causation, and the circumstances under which impaired attention is a problem.

8.1 *The Role of Attention to the Road Environment in Crashes*

There is no dispute that driver error, or the human factor, is involved in the great majority of road crashes. Percentages of crashes due in part or wholly to driver error are as high as 90% of all crashes according to some sources (Sanders & McCormick 1993). In the last decade there have been several attempts to identify the importance of driver inattention in causing crashes. By inattention is meant a failure on the part of the driver to react appropriately to the road environment. It is believed that driver inattention in all its forms is the major cause of crashes. The causes of driver inattention can range from outright ‘asleep at the wheel’, through ‘faulty visual surveillance’, ‘looking but not seeing’, to ‘attention to competing events, thoughts and objects’.

The onset of fatigue will precipitate one or more of these types of attentional failure, although they may also result from other causes such as using a mobile phone. The precise terminology used to describe the attentional failure depends upon the data available to the study and the authors conceptions. Changes to the road and vehicle environment is one major way of combating driver fatigue and inattention as a cause of crashes.

8.1.1 Varieties of Inattention to the Road

Several major US studies have addressed the importance of inattention in crash causation. The tri-level Indiana study (Treat et al, 1979) was the largest study on the issue. It found 'recognition failure' accounted for 56% of crashes. Recognition failure involved 'faulty visual surveillance- 23% of crashes', 'preoccupation with thoughts - 15% of crashes', 'attention to other events, activities and objects in vehicle - 9%', 'attention to other external events - 4%' and 'asleep at the wheel - 4% of crashes'. Najm, Mironer, Koziol, Wang and Knipling (1995) found from 700 cases in the Crash Worthiness Data System and General Estimates System that recognition failures caused 45% of crashes and that drowsiness caused an additional 3.7% of crashes. The studies described above report only a small percentage of drivers asleep at the wheel and thus extremely fatigued. Several other studies (NTSB, 1995) report much higher percentages of crashes are due to fatigue. This is because the other studies attributed fatigue as a crash cause to many cases of inattention as well as 'asleep at the wheel'. These latter studies confirm much laboratory research that shows inattention due to fatigue ranges along a dimension from infrequent attentional lapses, through microsleeps to full sleep.

8.1.2 Varieties of Inattention and Types of Crashes

Recently, NHTSA has employed the National Accident Sampling System of Crash Worthiness Data Systems to better delineate the problem of inattention by addressing all available sources of information about crash causation (Wang, Knipling and Goodman, 1996).
This involved analysis of over two and a half million tow-away crashes and over four and a half million drivers. Over 2.5% of crashes involved a driver asleep, over 13% involved distraction, nearly 10% were due to the driver looking but not seeing a hazard, and over 28% were crashes in which the driver was not found to be inattentive. As Table 1 shows, of crashes due to sleepiness, 66.8% were involved single vehicle crashes and 27.9% were

involved rear end collisions. Of crashes due to distraction 41.2% involved single vehicle crashes and 9.6% involved read end collisions. Of crashes due to looking but not seeing 15.8% involved read end collisions and 71.3% involved lane manoeuvres. Inattention was a less important cause of crashes when the weather was adverse although the interpretation of this finding is equivocal.

Table 1: Crash type by crash cause. From Wang, Knipling and Goodman, (1996)

Crash Type Row% Column%	Sleepy	Distract	LBNS	Unknow n	Attentive	Total
Single Vehicle	5.8 66.8	18.1 41.2	9.2 0.7	31.8 20.6	44.0 47.0	99.9 30.3
Rear-End/LVM	12.7 27.9	21.3 9.6	3.4 2.0	48.3 6.4	14.3 3.0	100 6.0
Rear-End/LVS		23.9 21.9	11.4 13.8	52.6 14.1	11.8 5.0	100 12.2
Int/Cross Path		7.0 18.1	17.9 63.6	52.8 39.8	22.3 27.2	100 34.5
Lane Change /Merge		5.6 1.6	17.2 6.7	41.8 3.4	35.2 4.7	100 3.8
Head-on	1.0 1.7	7.0 2.2	8.1 3.5	46.4 4.3	37.5 5.6	100 4.2
Other		7.8 5.4	10.4 9.8	57.3 11.4	24.0 7.6	100 9.1
Total crashes	2.6 100	13.3 100	9.7 100	46 100	28.4 100	100 100

Abbreviations: LBDNS=looked but did not see; LVM=lead vehicle moving; LVS=lead vehicle stopped; Int=intersection.

8.1.3 When and Where Inattention Occurs

Wang, Knipling and Goodman (1996) found sleepiness was over represented as a cause of high speed crashes and crashes on high speed limit roads; 38.4% of sleepiness crashes occur travelling at 65 mph and over. This finding is confirmed by Maycock (1995) who found 15% of all crashes on motorways were due to fatigue but only 7% of urban crashes were due to fatigue. Sleepiness is over represented among crashes after midnight and midday. By contrast, distraction and looking but not seeing were important as causes of crashes during morning and afternoon rush hours. Importantly, younger drivers aged 25-34 were heavily over represented in sleepiness crashes, and contributed 40% of sleepy drivers. Garder and Alexander (1994) also confirmed the finding that younger drivers are significantly more likely to fall asleep than older drivers. Wang et al. found drivers over 65 years were heavily under represented in sleepiness crashes. Maycock (1995) also found older drivers were under represented in fatigue related crashes. Male drivers were five times as likely as females to be involved in sleepiness crashes. Sleepiness was greatly over represented in crashes where the driver was ‘going straight’ and made no avoidance manoeuvre before the crash (62.2% of sleepy crashes). Distraction was a major cause of crashes whilst negotiating a curve and looking but not seeing was a major cause of crashes at intersections.

8.1.4 The Propensity to Fall Asleep at the Wheel and Crash

Garder and Alexander (1994) surveyed 205 drivers comprising students and shoppers about falling asleep while driving a motor vehicle. Over 30% had fallen asleep at the wheel during the previous 12 months; over 15% had fallen asleep twice and 13% had fallen asleep several times.

Maycock (1995) also found that 29% of the drivers he studied had felt close to falling asleep at the wheel in the past year. By extrapolation Garder and Alexander suggest that the incidence of dozing off is about once every 32,000 kms.

Garder and Alexander found the frequency of falling asleep at the wheel was unrelated to exposure or distance driven in a year. Those who drove the longest distance were no more likely to fall asleep at the wheel than those who drove the shortest distance. Maycock (1995) has found among truck drivers that accident rate is independent of exposure; people who drive up to 40,000 miles per year have the same number of accident as those who drive over 100,000 miles per year. Studies of car drivers' accident rates also show that they flatten off at high mileage's and this results in no increase in crash rates with increasing exposure to high mileage's.

Garder and Alexander found that of those drivers who had fallen asleep at the wheel, 13% reported it resulted in a collision and a further 2% left the road. Thus 7% of all drivers surveyed had a crash due to falling asleep. The collisions occurred with other vehicles and stationary objects. Only two out of their 15 drivers woke up before the impact. Maycock's (1995) study of UK car drivers also revealed that 7% of his drivers attributed their accidents to tiredness. Thus in Maycock's sample about 9-10% of all accidents are caused by tiredness.

8.2 Truck Drivers' Crashes due to Fatigue

In Australia, Haworth et al. (1989) found from Coroners' reports, that 9.1% of fatal truck crashes involved fatigue. A further 25% of fatal truck crashes were deemed to involve driver inattention by the Coroner. Haworth et al analysed the data further using additional criteria to the Coroners reports.

These were: long hours of work without breaks; insufficient recovery periods, a long pre-trip activity and evidence of falling asleep at the wheel. When these criteria were taken in to account, nearly 20% of truck crashes involved fatigue on the part of truck or car drivers. In these crashes 7.4% involved fatigue in the truck driver and 12.4% involved fatigue in the car driver.

Haworth and Rechnitzer (1993) have examined the characteristics of fatigue related crashes. They reinforce many of the conclusions from Wang, Knipling and Goodman, (1996). Haworth and Rechnitzer (1993) found that relatively more fatigue crashes occurred between midnight and 6 am and relatively fewer fatigue crashes occurred between noon and midnight. Table 2 contrasts rigid and articulated truck crashes by States according to time of occurrence.

Table 2: Time of occurrence of rigid and articulated truck crashes by State in 1992 (Fatal File FORS)

State	*Number of all crashes*	*Crashes from midnight to 6am*	*Crashes from midnight to 6am: Percent of all crashes*
NSW	114	34	29.8
Victoria	51	9	17.6
Queensland	69	10	14.5
SA	16	3	18.8
WA	21	2	9.5
Tasmania	4	1	25.0
NT	3	1	33.3

Haworth and Rechnitzer (1993) found that fatigue was over represented in crashes when the driver was more than 50 kms from home .

Table 3 shows crashes in 1992 by State where the distance from home was greater than 50 kms. for rigid and articulated trucks. The proportion of crashes more than 50 kms from home forms about 50% of all crashes.

Table 3: Rigid and articulated truck crashes where distance from home exceeded 50 kms in 1992 (Fatal File FORS)

State	***Number of all crashes***	***Crashes over 50 kms from home***	***Crashes over 50 kms from home: Percent of all crashes***
NSW	120	71	59.2
Victoria	53	22	41.5
Queensland	69	30	43.4
SA	16	5	31.3
WA	22	10	45.5
Tasmania	4	2	50.0

NT	3	1	33.3

Haworth and Rechnitzer (1993) also found that in half of the fatigue related crashes the vehicle drifted off a straight road (Off path, on straight) as compared to 14.8% of non fatigue related crashes attributable to this manoeuvre. A further 23.4% of fatigue related crashes involved the vehicle drifting of the road on a curve. Thus close to 75% of fatigue crashes involve these two manoeuvres. These findings parallel those the type of crash of all drivers reported by Wang et al. (1996) Table 4 shows rigid and articulated truck crashes attributable to drifting off the road on the straight and on a curve.

Table 4: Rigid and articulated truck crashes attributable to drifting off a straight or curved road in 1992 (Fatal File FORS)

State	***Number of all crashes***	***Crashes off path***	***Crashes off path: Percent of all crashes***
NSW	114	14	12.3
Victoria	51	4	7.8
Queensland	69	11	15.9
SA	16	1	6.3
WA	21	3	14.3
Tasmania	4	1	25.0
NT	3	1	33.3

8.3 Summary of the Causes and Consequences of Fatigue and Inattention Crashes

In summary, the US data on crashes in which the driver is asleep at the wheel suggests it is 2.6% of all crashes. Crashes due to distraction from day dreaming and other events and looking but not seeing hazards, which are also symptoms of fatigue, are relatively more common and constitute about 23% of total crashes in the US data. Thus upto 25% of all US crashes are due to failures of attention on the part of the driver either because of outright sleep or attentional lapses due to the onset of fatigue or other possible causes. Australian data on truck drivers suggest that between 13% and 20% of crashes are due to fatigue although this figure is based on coronial conclusions of fatigue involvement because no other cause of the crash could be determined.

About 30% of drivers report being near to sleep or actually falling asleep at the wheel in the past year (Maycock, 1995; Garder and Alexander, 1994). Seven percent of those drivers report a crash due to falling asleep in the last year (Garder and Alexander, 1994; Maycock, 1995). Falling asleep at the wheel is not uncommon but only one quarter of episodes of sleep result in a crash.

Fatigue and inattention crashes are typically severe because between one half and two thirds of such crashes involve no avoidance manoeuvre prior to the crash and they are typically high speed crashes. It is not clear why fatigue is over involved in high speed as compared to low speed crashes; high speed driving environments may be more monotonous, longer in duration and less forgiving of attention errors than low speed environments. Between two thirds and three quarters are single vehicle run-off road crashes; the remaining crashes are rear-end collisions with a vehicle ahead. At least half of severe fatigue and inattention crashes occur more than 50 km from the driver’s home and involve rural driving.

The foregoing data on the number and characteristics of fatigue related crashes suggest that road based countermeasures will have considerable impact on reducing fatigue and inattention related crashes if they can alert the driver to the task of driving and minimise the severity of a crash. The cost and practicality of road based countermeasures for rural roads needs to be considered in the light of the frequency and severity of rural crashes due to inattention and fatigue. Countermeasures to fatigue and inattention crashes are of two types: countermeasures that reduce the frequency of these crashes by alerting the driver; and countermeasures that reduce the severity of these crashes by mechanical means.

8.4 The Road Environment and Fatigue

The road environment has both the potential to cause fatigue and to provide countermeasures to it. There is a little evidence of the extent to which the road environment contributes to fatigue. As Maycock (1995) and Wang, Knipling and Goodman (1996) have found, high speed roads have more than their fair share of fatigue related crashes. Maycock found twice as many fatigue related accidents on motorways in the UK as in urban areas despite the better safety record for crashes on motorways. Although this may indicate high speed driving is less forgiving of attentional errors than urban driving it may also indicate that road environment factors cause fatigue by decreasing alertness and promoting sleepiness.

Typically high speed driving on freeways and motorways is more monotonous and of longer duration than urban driving experiences. This suggestion is particularly true of Australian high speed rural driving conditions. Conversely, since greater distances are covered by drivers on freeways and on rural roads in Australia, fewer fatigue related crashes occur per kilometre travelled on freeways and rural roads than on urban roads. Nevertheless these findings do suggest that monotonous driving conditions could contribute to fatigue. It is noteworthy that Hartley et al. (1996) reported that eastern states truck drivers find the road environment a major cause of fatigue, and improvements to the road environment a very desirable countermeasure to fatigue.

8.5 Countermeasures that alert and re-engage the fatigued and inattentive driver

Driving is almost entirely a visuo-motor task. That is, driving is a tracking and control task conducted under visual guidance. Countermeasures to inattention must therefore concentrate upon re-engaging visual control of the task. Since the attentional failure is visual, countermeasures must focus primarily on non visual means of alerting the driver. However, some visual road based measures that assist the driver who has declining visual control of driving may also be of benefit.

Road based measures which have the potential to achieve the objective of alerting and re-engaging the driver or improving the drivers' visual control are:

Raised pavement markers

Rumble strips

Painted edge lining

Reflective guide posts

8.6 Countermeasures that minimise the severity of fatigue and inattention crashes.

Countermeasures to reduce crash severity will include steps to reduce the mechanical deformation of the vehicle if there is an impact, and steps to reduce the probability of a crash when lane tracking is impaired by fatigue and inattention. These are:

Removal of trees

Breakaway poles

Crash attenuators

Wide median strips and with barriers

Clear zones adjacent to the seal

Paved shoulders

Culvert protection

8.7 Evaluation of Potential Countermeasures to Fatigue and Inattention Crashes

Pak-Poy and Kneebone (1988) have conducted a cost benefit analysis of a variety of road based measures to improve road safety. Many of the measures have considerable implications for reducing fatigue and inattention crashes since they have the potential to re-engage the driver to the task and for reducing the severity of these crashes. These countermeasures are evaluated in Table 5.

8.8 Recent Research

8.8.1 Shoulder Treatment and Rumble Strips.

Since 1990 the New York State Thruway Authority has evaluated an implemented program of Shoulder Treatment for Accident Reduction (STAR) (Shafer, 1993). As described above, run off straight and run off curve form upto 75% of fatigue and inattention crashes. The treatment consists of shallow grooves cut into Thruway shoulders generating vibration and noise when traversed by a vehicle. They can thus auditorily alert the visually inattentive driver of departure from the roadway. The grooves are 16 inches long an half and inch deep. More than 100 miles of STAR at three locations have been treated. In the 30 months prior to treatment 20 run off road crashes occurred at the 3 locations. In the 36 months since grooves were installed there have been zero run off road crashes in those areas. Two run off road crashes occurred within one mile of the treatment area in this period.

Table 5: Road based counter measures adapted from Pak-Poy and Kneebone (1988), with additional comments on the potential countermeasures by the present authors.

Road based countermeasures	Potential benefit to fatigue & inattention crashes	Benefit to Cost Ratio
CHEAP TREATMENTS		
Shoulder treatment & rumble strips	**Recent research shows very great benefit to fatigue crashes**	**200:1**
Intersection signage	**Probably ineffective for fatigue & inattention**	**>200:1**
Warning signs	**Probably ineffective for fatigue & inattention**	**>125:1**
100 mm edge line	**Willis (1984) suggests reduction of 35% in out of control crashes; of benefit to fatigue**	**10:1**
150-200 mm edge line	**Moses (1986) & US study suggests 34% reduction for out of control crashes v. 100 mm**	**10:1**
Removal of trees	**Good benefit for fatigue run off road crashes**	**10:1**
Raised reflective pavement markers	**Moses (1985) suggests ~20& crash reduction - good for fatigue because audible too**	**8:1**
Reflective guide posts	**Benefit at night could be ~30% - good for fatigue at night**	**8:1**
Installing breakaway or slip poles	**Extremely high benefit to fatigue related run off road crashes**	**7:1**
Intersection sight distances	**Some limited benefit for fatigue in rural crashes**	**5:1**
Crash attenuators	**Potentially useful for fatigue but limited applicability in rural environments**	**?**
MODERATE COST		
Surfacing & sealing	**Good for fatigue since recovery from out of control vehicle enhanced by sealing**	**9:1**
Turning lanes	**Probably limited benefit to fatigue crashes**	**5:1**
Lane width	**No evidence of benefit over 3.5 m width**	
Wide median strip	**Very good benefit to fatigue run off road crashes upto 10m width of strip**	**3:1**
Median with barrier	**Questionable benefit for fatigue**	**0.8:1**

	unless very narrow median strip	
Railroad crossing measures	Unknown, but possible benefit to inattention crashes	~0.5:1
Clear zone	Good benefits to fatigue crashes upto 9 m clear	?
HIGH COST TREATMENTS		
Two metre sealed shoulder	Good benefit for fatigue, especially rural crash	12:1
Overtaking lane	Of potential benefit since fatigue increases risky manoeuvres but unknown for fatigue	>3:1
Short 4 lane sections	Of potential benefit since fatigue increases risky manoeuvres but unknown for fatigue	>2:1
Stopping sight distance	Some potential benefit for fatigue when surveillance & reaction time is impaired	2:1
Reducing horizontal curvature	Unknown, but potentially great for fatigue by reducing run off curve crashes	2:1
T intersections	Unknown, but possible benefit to inattention crashes	>1:1
Superelevation and crossfall	Unknown, but potentially great for fatigue by reducing run off curve crashes	<1:1

In a comparable study in California, a 49% reduction in run off road crashes was found following shoulder treatment by rumble strips (Chaudoin and Gary, 1985). The Pennsylvania Turnpike Commission has found a 70% reduction of run off road crashes following the introduction of shoulder rumble strips (Wood, 1990)

Garder and Alexander (1994) reviewed the effectiveness of rumble strips. They conclude that over 80% fewer run off road crashes have been reported after installation of rumble strips. The studies they reviewed controlled for exposure. The benefit to crashes in monotonous terrain is greater than in more varied landscape areas. These authors also note that centre line rumble strips have been adopted in some US states with success.

8.9 Recent Experimental Approaches to Road Design

De Waard, Jessurin, Steyvers, Raggatt, and Brookhuis (1995) have studied the impact of road layout on the speeding behaviour of drivers. This study represents one of several recent efforts to empirically test the impact of changes to road layout on drivers' on-road behaviour in an effort to improve safe driving behaviour. In rural Holland speeding on single lane roads is a persistent road safety problem that has proved difficult to control. De Waard et al. hypothesised that changes to the road lay out which increased the rate of information which drivers' needed to process would increase drivers' mental work load. They supposed that an increase in work load could cause drivers' to drop their speed as they attempted to reduce the rate of information they had to process to a tolerable level whilst driving. The authors reduced the road width by placing blocks of gravel chippings along the centre line and at intervals on the road edge. Driving over these blocks also produced unpleasant sounds and vibration in the vehicle.
Using a vehicle instrumented to measure speed, heading and heart rate variability, the authors found that speed and swerving behaviour were reduced by the treatment. There was also a decrease in heart rate variability indicating

an increased mental work load in drivers traversing the experimentally treated roads. They conclude that experimental infra structure changes to the road layout have a useful role to play in moderating drivers behaviour and improving road safety in otherwise difficult to control road environments.

It is anticipated that a number of other proposals for experimentally treating road layout will be undertaken in the future and possibly adopted for limited use in difficult to control environments.

8.10 Future Prospects for Developing Road Based Safety Treatments

In undertaking the present review of road based countermeasures it became apparent that data on the evaluation of the safety benefits of many treatments for the driving population was quite unsatisfactory. Evaluations were usually based on crash rates before and after the introduction of a specific treatment. The findings were often variable, contradictory and inconsistent. It became apparent that this state of affairs was due to several factors. Firstly, before versus after treatment data was often not available; if it was available it was often confounded by changes in the rate of traffic flow over the treated stretch of road. Second, the same treatment was often implemented on very different stretches of road, and in different ways, with the consequence that different studies of the same treatment produced dissimilar findings. Thirdly, some improvements to road safety were probably small and significant but the improvements to safety were obscured by considerable variability in the data collected due to changes in weather, traffic flow and other factors.

Fourthly, data was often not collected over long enough, or comparable enough, periods to enable an adequate comparison of the treatment with no treatment. Finally, crashes may result from many different causes such as fatigue versus adverse weather; whereas a specific treatment may reduce one crash cause, such as fatigue, it may have little or even a negative impact, on other causes such as adverse weather conditions. The result of this unsatisfactory state of affairs is that:

- it is often impossible to tell whether a treatment is effective in improving safety;
- some beneficial and cheap treatments may be overlooked for lack of adequate data;
- some treatments effective in some conditions may be adopted for other road conditions where they have no benefit to safety;
- some potentially effective treatments may be inappropriately implemented.

The solution is clearly to adopt a research strategy which provides direct and immediate data on driver performance on the road before and after the treatment has been introduced. If the results are positive only then is it appropriate to collect data on population road safety. This strategy is cost effective because

- it provides immediate information on whether the treatment has the potential to improve driver performance on the road;
- it identifies the type of driving situation where a benefit may be expected;
- it provides information on whether the implementation is potentially effective in the specific road setting where it is implemented;
- it provides information on the types of driving situation where the treatment has potentially adverse effects.

8.10.1 Using an Instrumented Car to study driver behaviour under different road treatment conditions.

The solution to the problem of the current unsatisfactory evaluation of road safety treatments is to use an instrumented car to study driver behaviour under different conditions of road treatment. Vehicles instrumented to record very many parameters of drivers behaviour are now commercially available, such as the DASCAR system develop by Oak Ridge National Laboratory on behalf of the National Highways and Transport Safety Administration in the USA. The instrumentation is unobtrusive so drivers are unaware that their driving behaviour is being recorded. Studies of the potential benefits of a treatment could be conducted by recording driver behaviour over the stretch of road for which a treatment is proposed. A mock-up of the treatment could then be implemented and driver behaviour recorded again. Driver behaviour could be easily recorded under many different conditions, such as during different weather conditions and traffic densities, at night and with driver fatigue. The instrumented car makes it easy to compare the benefits of implementing a treatment at one location with the benefits recorded at another treatment location. Thus enables authorities to implement the full treatment only in road conditions where it is likely to be effective and not waste money on implementing it where it will be of uncertain, or even negative, benefit.

8.11 Conclusions

8.11.1 What we know about fatigue & inattention crashes and effective countermeasures

- A small percentage of crashes are caused by sleep but many more drivers fall asleep at the wheel and do not crash;
- A considerably higher percentage of crashes involve inattention which arises from fatigue and other causes;
- Fatigue and inattention crashes are usually single vehicle, run-off road or rear end collisions;
- Fatigue crashes are relatively more frequent at night, among the young, on high speed roads and in rural settings; fatigued crashes are no more frequent among long than short distance drivers;
- Effective countermeasures to preventing fatigue and inattention crashes will involve alerting the driver to re-engage in the task of driving; effective countermeasures will be mainly non-visual.
- Effective countermeasures to minimise the severity of fatigue and inattention crashes will be to reduce the potential for impact with objects on the road and adjacent to the road;

- Countermeasures found to be effective are: edge lining, shoulder rumble strips, raised pavement markers, clear zones adjacent to the road including tree removal, breakaway or slip poles, sealing, adequate lane and median strip width and sealed shoulders.

8.11.2 What we do not known, and should know, about fatigue crashes & effective countermeasures

- Little is definitely known about the contribution of the road environment to causing fatigue and inattention crashes; this has implications for future road design criteria;
- Little is definitely know about the effectiveness of rest break intervals and duration's in preventing fatigue and inattention; these have implications for rest areas and facilities;
- Nothing is known about how the road environment might be changed to reduce fatigue and inattention developing, this needs empirical study;
- Evaluation of effective road based countermeasures to fatigue and inattention crashes is poor and much needs to be done to develop a good methodology for their evaluation;
- New, inventive, cost effective, road based countermeasures to fatigue crashes are urgently needed; a good methodology for their rapid evaluation is required if they are to be developed;
- Road design standards urgently need revision to take account of knowledge about the causes and characteristics of fatigue and inattention crashes;
- Countermeasures which may have the potential, but are unknown to be effective against fatigue and inattention crashes are: centre line rumble strips, wider edge lining, crash attenuators, crash barriers on narrow median strips, overtaking lanes and short 4 lane sections, improving stopping and intersection sight distances, judicious signage, reducing horizontal curvatures and improving superelevation and crossfall.

8.12 Recommendations

It is apparent that a considerable amount of research needs to be done to establish criteria for good road design standards for fatigue and inattention. Current design standards are based on the premise that drivers are actively engaged in the visual control of tracking and control and the standards are set to permit safe, attentive, driving within prescribed limits. Paradoxically, the same standards may encourage the development of fatigue and inattention. Thus, roads designed to permit attentive drivers to travel safely at high speeds may encourage the development of fatigue and inattention because they require minimal vehicle control on the part of the driver. The balance between road design criteria that encourage safe, attentive driving, but make so few demands on the drivers attention that inattention develops, needs to be struck.

- Research is needed on road design criteria that maximises safety but also requires active attention to the road environment.

It was also apparent in preparing this report that the evaluation of the road environment from a road safety perspective was inefficient. The principle mechanism to improving road safety on existing roads is the identification of ‘black spots’ based on road user population crash statistics. This process is time consuming, expensive and costly in terms of lives. It is also inefficient in providing very ‘noisy’ results contaminated by many factors. It provides little useful information about the causes of crashes and the success of road based treatment countermeasures.

- The current evaluation methodology of road standards and crash countermeasures is unsatisfactory and needs urgent revision to encourage the rapid elimination of poor road design and the development of new innovative, countermeasures.

New technological developments of in-vehicle instrumentation permits all the important parameters of driving behaviour in response to the road environment to be measured unobtrusively. This technology therefore lends itself to the rapid assessment of specific road environments and standards including road based treatment countermeasures. The methodology would involve assessing real on-road driving behaviour in specific road environments and under a variety of driving conditions. Road environments, in different driving conditions, which lead to poor vehicle control could be rapidly identified. Countermeasure treatments could be proposed and rapidly evaluated for improvements in vehicle control. Unsuccessful treatments could be immediately rejected in favour of better treatments. The applicability of specific treatments to specific road environments could be evaluated and implemented selectively where they prove beneficial.

The use of population crash statistics would be enhanced by improved knowledge of the causes of poor vehicle control derived from use of the instrumented vehicle. The process of improving road safety by design would be accelerated, and reduced in monetary cost and loss of life.

- The development of an instrumented vehicle methodology for road standard and countermeasure evaluation is urgently required.

8.13 References

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