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FATIGUE IN TRUCK ACCIDENTS

by

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Abstract:

Based on Coroners' verdicts, fatigue of car or truck drivers was a contributing factor in 9.1% of fatal accidents involving trucks. Based on the presence of factors such as extended driving hours, falling asleep at the wheel, comments about tiredness, driving right of centre and night-time driving, the authors estimated fatigue contributed to 19.9% of the accidents. There were approximately equal numbers of fatigued car drivers and truck drivers.

An analysis of casualty and fatal truck accidents by time of day (adjusted for exposure) showed that accident risks were highest during the night on all five Victorian highways studied. Driver fatigue is one of the possible factors underlying this pattern of elevated risk.

The report section described in-vehicle fatigue counter-measures. The distinction between fatigue monitors and alerting devices was made and it was recommended that eye closure and head nodding monitors and an alerting device be tested in the next stage of this project.

Key Words:
Fatigue (human), accident rate, fatality, safety, driver, attention, hour, Victoria

Disclaimer

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EXECUTIVE SUMMARY

This report is one of several to be produced as part of a study of driver fatigue in truck accidents. It presents two estimates of the involvement of fatigue in Victorian truck accidents and a review of in-vehicle fatigue countermeasures to select devices for testing in the second stage of the project. The study was commissioned by the Victorian Road Freight Transport Industry Council and funded by the Road Construction Authority of Victoria in May, 1988.

Coroners' reports were analysed to

- provide an estimate of the degree of involvement of fatigue in fatal Victorian accidents involving trucks which occurred in the period 1984-86 and to
- collect preliminary data on the incidence of mechanical defects in the sample of fatal accidents involving trucks.

The Coroner concluded that fatigue was a contributing factor in 9.1% of the sample of fatal accidents involving trucks. This figure was made up of car-driver fatigue in 5.4% of the accidents, articulated vehicle-driver fatigue in 3.2% of the accidents and fatigue on the part of rigid truck drivers in 0.5% of the accidents. (The differences between car and truck drivers are not statistically significant.)

An alternative estimate of the contribution of fatigue was calculated by classifying as fatigue-related those accidents which involved several of the factors: extended driving hours, evidence of falling asleep at the wheel, comments about tiredness, driving right of centre in the absence of elevated BAC and night-time driving. This resulted in a judgement that fatigue was involved in 19.9% of the sample of fatal accidents involving trucks. This figure was made up of fatigue on the part of car drivers in 12.4% of the accidents, fatigue of drivers of articulated vehicles in 6.5% and fatigue of drivers of rigid trucks in 1.1% of the accidents. The percentage of car drivers fatigued is statistically significantly greater than the percentage of articulated vehicle drivers.

Both estimates from Coroners' verdicts and the authors' judgement may be unreliable because of selective reporting in the Coroners' records lowering the estimates of fatigue in accident-involved truck drivers. Truck drivers more often survive the accident to provide witness information, which may bias the available evidence.

Truck mechanical defects were considered by the Coroner to have been a probable cause in five crashes and a possible cause in another four crashes. Tyre defects were the most common type of mechanical defect for both articulated and rigid vehicles. For articulated vehicles, five of nineteen owner-driven trucks had a defect (26.3%) and three of 58 trucks driven by another person were defective (5.1%). There were few defects in rigid trucks. While these results are in accord with the concern about maintenance neglect by owner-drivers, the results are based on such a small number of defects that such an interpretation may be premature.

An estimate of the involvement of fatigue in all accidents involving trucks as an exposure-corrected function of time of day was calculated from data obtained from the Road Traffic Authority's accident data base and traffic counts made by the Road Construction Authority. The analysis showed that accident risks were highest during the night on all five Victorian highways studied. Driver fatigue is one of the possible factors underlying this pattern of elevated risk.

The third section describes in-vehicle fatigue countermeasures and recommends devices for testing in the second stage of the project. Devices to monitor levels of driver fatigue based on psychophysiological measures of fatigue (eye closure and head nodding monitors) and measures of vehicle control behaviour (monitors of steering pattern and tachographs) are discussed. Fatigue countermeasures which function by maintaining driver alertness include reaction time devices (e.g., Roadguard) and driver strategies (auditory input, control of cabin temperature and alerting 'games').

It is recommended that the Onguard eye closure monitor, a head nodding monitor and the Roadguard alerting device undergo laboratory testing in the next stage of this project. The criteria which will be applied in testing are reliability, criterion level and degree of intrusiveness.

A separate volume has been produced which presents information about the onset of fatigue to enable the development of an educational program for heavy vehicle drivers to assist in the prevention of fatigue-related accidents.

1 INTRODUCTION

A general overview of truck accidents, with particular emphasis on Australian findings, and a discussion of the role of fatigue in truck accidents is provided in Chapter One.

In order to identify the scope for fatigue countermeasures, Chapters Two and Three present estimations of the involvement of fatigue in Victorian truck accidents.

The primary objective of this study was to investigate the potential of fatigue countermeasures. Chapter Four presents a review of in-vehicle fatigue countermeasures to select devices for testing in the second stage of the project. Fatigue countermeasures based on education are discussed in a separate volume entitled *Information for development of an educational program to reduce fatigue-related truck accidents*.

1.1 AN OVERVIEW OF TRUCK ACCIDENTS

Initiatives to reduce the frequency of truck accidents should be given a high priority because trucks (particularly articulated vehicles) have a high accident exposure in terms of distance travelled and because truck accidents are often more severe than those involving only cars.

The survey of motor vehicle usage conducted by the Australian Bureau of Statistics for the year ending 30th September, 1985 showed that, on average, semi-trailers travel 4.6 times as far as cars in a year and that rigid trucks travel 1.2 times as far as cars.

Analysis of accident data suggests that truck accidents are more severe and that the rate of accident involvement of trucks as compared with other types of vehicles depends upon the severity level studied.

Accidents between trucks and cars are likely to be severe because the much greater mass of the truck imposes large forces on car occupants during collisions. Analysis of Road Traffic Authority data (reported by Vulcan, 1987) showed that only about 22% of those killed and 17% of those injured in truck crashes were occupants of the truck. Thus, reducing truck accidents would substantially improve the safety of other road users.

On average, accidents involving trucks are more severe than accidents involving other types of vehicles only. Vulcan (1987) derived involvement rates (per 100 million vehicle kilometres) of articulated vehicles, rigid trucks and cars and station wagons from information presented to the National Road Freight Industry Inquiry (May, Mills and Scully, 1984). As Table 1 shows, for hospital admissions accidents, an articulated vehicle is about twice as likely to be involved as a rigid truck and is less likely to be involved than a car/station wagon. However, an articulated vehicle is more than four times more likely to be involved in a fatal accident than a rigid truck and about three and a half times more likely to be involved in a fatal accident than a car/station wagon.

These values are national averages and it is recognised that accident rates may vary considerably for different sectors of the road transport industry.

Table 1. Rates of involvement of cars and station wagons, rigid trucks and articulated vehicles in casualty and fatal accidents. Rates are expressed as number of accidents per 100 million vehicle kilometres. Data from Vulcan (1987).

	Casualty accidents	Fatal accidents	Ration of casualty to fatal accidents
Cars/station wagons	21.7	2.1	10.3
Rigid trucks	10.3	1.7	6.1
Articulated vehicles	19.0	7.4	2.6

1.2 THE NEED TO STUDY DRIVER FATIGUE IN TRUCK ACCIDENTS

In the last 20 years evidence has accumulated that suggests that fatigue may be a significant contributor to truck accidents (e.g., the findings of Harris and Mackie, 1972; Mackie and Miller, 1978; Linklater, 1980). In the early part of this period, the US Bureau of Motor Carrier Safety (1970) concluded that 30 per cent of US single-vehicle truck accidents appeared to have involved a sleeping driver. Two recent studies investigated truck accidents in the western United States. Transportation Research and Marketing (1985) concluded that fatigue was a primary cause in 41% of heavy truck accidents and a probable cause in a further 18%. Jones and Stein (1987) conducted a study which found that the accident risk for drivers of articulated vehicles who had driven for more than eight hours was double that of drivers who had driven for less than eight hours. These data suggest that any program which reduced levels of driver fatigue in the United States could lead to a substantial reduction in truck accident rates.

The magnitude of the contribution of fatigue to truck accidents in Australia is not so clear. While several Australian reviews of the fatigue literature have been compiled (Fell, 1987; Haworth, Triggs and Grey, 1988; Nairn, 1987), no in-depth investigation or case-control study of truck accidents has been conducted. There is some scattered evidence from New South Wales and Queensland which suggests that the US experience is likely to be similar in Australia (Linklater, 1978, 1980; McDonald and McDonald, 1983). However, fatigue levels among truck drivers in other states may differ because of different driving hours limitations.

In a Tasmanian study, Leggett (1988) found that the contribution of fatigue increased with accident severity, mainly because of the often fatal nature of single-vehicle run-off-road crashes. Analysis of all reported accidents showed a slightly lower involvement of fatigue in rural single-vehicle truck than car accidents. When property damage accidents were removed from this sample, however, fatigue was shown to contribute more to truck than car accidents. Another important finding was that the likelihood of the truck driver being killed was greater in fatigue-related accidents than in other accidents.

Some information about the contribution of car driver and truck driver fatigue to accidents can be obtained from recent in-depth studies. Armour, Carter, Cinquegrana and Griffith (1988) conducted a study of rural single-vehicle acidents in Victoria which resulted in casualties. It was considered probable that the driver had fallen asleep in 27% of the cases investigated. Of 147 crashes, twelve accidents involved trucks. The truck driver was asleep in two crashes and was possibly fatigued in a third crash.

Ryan, Wright, Hinrichs and McLean (1988) carried out an in-depth study of crashes on rural roads near Adelaide. When all accident-involved drivers were asked, 31.4% responded that they had felt slightly, moderately or very fatigued just prior to the accident. The percentage reporting fatigue was higher for truck drivers (41.7%) and motorcycle riders (50.0%). In two of nine crashes of articulated vehicles it is likely that the driver fell asleep.

The need for further research into the relationship between fatigue and truck accidents has been highlighted by the recent decision of the Australian Transport Advisory Council (ATAC) to recommend changes in driving hours legislation. To quote the ATAC press release:

> Ministers agreed on revised driving hours in the eastern States with enhanced log book information and the optional use of tachographs. The revised driving hours reflect modern industry conditions and allow a maximum 6 hours driving shift, 15 hours daily, 75 hours weekly and 150 hours fortnightly.

This is an increase from the present Victorian limits for hours of driving which allow a maximum five hour driving shift, 12 hours daily and 72 hours weekly.

1.3 RESEARCH OBJECTIVES

The first objective addressed in this study was the estimation of the contribution of driver fatigue to Victorian truck accidents in order to identify the scope for fatigue countermeasures. The second objective addressed was the selection of potential in-vehicle countermeasures for testing in the second stage of the study.

Estimates of the involvement of fatigue in Victorian truck accidents were developed by two indirect methods: an examination of Coroners' records and an analysis of the time of day pattern of accidents. The first method was a surrogate for an in-depth study and the second allowed the use of a readily available proxy for fatigue, time of day.

The decision was made to use Coroners' records as one data source to enable the analysis of information about variables relevant to fatigue, such as trip length, sleep and rest pattern prior to the accident and evidence of falling asleep at the wheel (driver admissions or evidence of a lack of corrective manoeuvres). It was intended that the Coroners' records would give more detail than the Road Traffic Authority's mass accident data base without the expenditure of time and financial resources needed to conduct an in-depth accident investigation study.

The use of Coroners' records necessarily restricted the analysis to fatal accidents involving trucks. Earlier studies suggest that the contribution of fatigue is greater to fatal accidents than to others of lesser severity (e.g., Leggett, 1988). Thus the estimate gained from the Coroners' records may overestimate the role of fatigue in all classes of accident (property-damage, casualty and fatal).

The second type of estimate of fatigue was developed by the use of a proxy measure, time of day. The number of accidents involving trucks in two-hour time periods was adjusted by a measure of exposure to provide risk estimates for different times of the day. In this sort of analysis, the presence of fatigue is supported by higher adjusted accident frequencies at night than during the day.

The accident-time of day analyses used accident data from the Road Traffic Authority's mass accident data base and truck volume counts provided by the Road Construction Authority. Both fatal and casualty accidents were include in the analysis. Thus, this analysis included a larger number of accidents than the Coroners' data (4552 vs. 186) and the estimate should be more readily generalisable across levels of accident severity.

2 ANALYSIS OF CORONERS' RECORDS

2.1 METHODOLOGY AND PROBLEMS WITH THE PROCEDURE

To estimate the relative importance of fatigue versus other factors (e.g., vehicle defects) in urban and rural areas, the Coroners' records of fatal accidents which occurred in the years 1984 to 1986 were examined.

A fine-grained analysis was attempted to determine whether the contribution of fatigue differed across various sectors of the industry. Details of a number of driver (of truck or other vehicle) and vehicle characteristics were examined. Driver variables recorded included length of time at the wheel (in that driving stint and for that trip), activities before driving, whether owner-driver or employee (in which case, name of company), reported presence of drugs, license details, departure point and configuration, type of load, age and whether mechanical defects were present which may have contributed to the accident. It is hoped that this fine-grained data will suggest hypotheses for further, more detailed studies of variables affecting truck safety.

Statistical analysis of the results included tests of differences of proportions (Ferguson, 1971, pp. 160-162) and chi-square tests to determine if any relationship existed between variables. For both tests the values of the test statistic (z or c2) and the significance level are reported.

It was planned to use Coroners' records for accidents that occurred during 1985-7 but the availability of Coroners' records caused some difficulties. Since the introduction of the new Coroners' Regulations on June 1, 1986 the number of full inquests has fallen. In some cases the evidence is heard by the Coroner in Chambers and the records contain little more than the Coroner's finding and in other cases there is no inquest and so no record is held. Hence it was decided to use the period 1984-86 during which a higher proportion of records were available. Of the 229 fatal accidents involving trucks in the years 1984 to 1986, Coroners records were available in 186 cases.

Overall, the extent of available information in the Coroners' records needed for this project was less than had been expected. For some variables information was missing for a large number of accidents or drivers. This was particularly a problem for details of length of time driving. There also seemed to be selective reporting in the Coroners' records: sometimes only variables which were thought likely to be important in that case were recorded.

A copy of the form used to record data from the Coroners' records and a listing of the variables recorded are presented in Appendix 1.

2.2 FATIGUE-RELATED VARIABLES

From the Coroners' records details of a number of variables were collected because these variables have been shown in past studies to be indicative of the level of driver fatigue. The variables are

- · state of registration
- · vehicle ownership
- · number of vehicles involved in the accident
- · day of the week

- · time of day
- · blood alcohol concentration.

A description of the patterns of these variables follows, with an outline of the research linking variables and fatigue-related accidents. Analyses of the Coroners' records of for state of registration and vehicle ownership are presented in the body of the report. For the other variables, more complete information (i.e., fewer missing cases) is available from the mass data system. Analyses of the Coroners' records of these variables are presented in Appendix 2.

State of registration. Out of state registered vehicles are more likely to be on a long trip than locally registered vehicles and so their drivers are more likely to be fatigued.

Herbert (1982, cited in National Roads and Motorists Association (NRMA), 1986) showed that the severity of articulated vehicle accidents in NSW (as shown by number of fatalities per crash) was 50% higher for trucks registered outside NSW than for those registered within the state. Furthermore, the number of fatalities per crash has increased more quickly for articulated trucks owned outside NSW than for locally registered semi-trailers during the period 1978-1981. "Interstate operators are more likely to be travelling greater distances per trip predominantly on rural highways than intrastate operators and thus their crash histories will reflect the nature of their operations" (NRMA, p. 11).

Vehicle ownership. There is a widespread view that the problem of truck driver fatigue is most severe among owner-drivers because these drivers are commonly under financial pressure to work long hours.

There are many owner-drivers. Early in 1984 the Bureau of Transport Economics carried out a survey of trucking operations, primarily to assist the National Road Freight Industry Inquiry in its data collection activity. There were 16,110 owner-drivers comprising almost one-half of hire and reward operators (those not operating as part of e.g. the agriculture and forestry industries). Some 72 per cent of business units operated only one truck, 17 per cent operated two trucks and only 11 per cent operated more than two trucks. Thirty-five per cent of owner-drivers had articulated trucks.

The BTE 1982-83 survey of trucking operations (BTE, 1986) showed that trucks operated by ancillary operators averaged 22,500 kilometres in 1982-83. Overall, owner-drivers averaged 53,000 kilometres in 1982-83 and owner-drivers operating over long distances (at least 100 km) averaged 112,300 kilometres. Trucks operated by non-owner-driver hire and reward operators averaged slightly more kilometres; 66,300 kilometres overall and 130,700 kilometres over long distance routes.

One has to be careful not to infer from these data that non-owner-drivers drove longer distances. It is possible that the longer distances driven by these trucks were achieved by spelling the driver without spelling the truck. An example would be a fleet truck which was driven to Sydney, unloaded and driven back immediately by a second driver. The fleet truck in this example would spend many more hours on the road than any of its employee drivers.

Number of vehicles involved in the accident. A number of studies have shown that the involvement of fatigue is greater in single- than multivehicle accidents. The Queensland Road Safety Research Group (1986) noted that "60% of this type of accident [single-vehicle] occurs between 10 pm and 6 am and are more prevalent toward the end of the working week. Few accidents of this type occur on weekends. This type of accident appears more prevalent with drivers aged 20 to 29 years and nearly always occur on highways away from populated areas" (p. 13).

Ogden and Tan (1987) found that there were few single-vehicle fatal truck accidents in urban areas. In rural areas, striking a fixed object or overturning occurred in most single-truck accidents. Articulated trucks were more likely to overturn off the carriageway, particularly on left-hand bends. This suggests the involvement of driver fatigue manifesting itself in lane drift.

In the South Australian rural in-depth study, five of the six accidents which resulted from drivers falling asleep were single-vehicle.

Day of the week. There is a suggestion that fatigue builds up throughout the course of the working week and so is greatest just before the weekend. The Queensland Road Safety Research Group (1986) stated that single-vehicle accidents, in particular, are more prevalent toward the end of the working week.

Alcohol involvement in accidents also varies by day of the week, being greatest during the weekend (McDermott and Hughes, 1983).

Time of day. Driver fatigue is most commonly experienced during the late night and early morning. In an analysis of US interstate truck accidents involving dozing drivers, Harris (1977) found that about twice as many of these crashes occurred between midnight and 8 am as in the rest of the day and about half of the single-vehicle accidents occurred in the early morning hours. Studies conducted in France (Hamelin, 1980, cited in McDonald, 1981) and Sweden (Lisper, Eriksson, Fagerstrom and Lindholm, 1979) have demonstrated similar patterns of results. Hoback (1959, cited in Lisper et al., 1979) stated that "a driver is fifty times more likely to go to sleep between 2 a.m. and 6 a.m. than from 8 a.m. to noon".

Time of day is not a pure meaure of fatigue, however, since other factors differ as a function of time of day. These factors include the degree of involvement of alcohol in accidents (McDermott and Hughes, 1983) and traffic density.

Blood alcohol concentration. Driver fatigue from lack of sleep or long working hours is made worse by alcohol. The effects of alcohol and fatigue are closely related because alcohol is a central nervous system depressant and makes a driver more likely to fall asleep. Even small quantities of alcohol (below .05 BAC) reduce alertness and simultaneously increase a driver's feelings of confidence (Ryder, Malin and Kinsley, 1981). This combination can lead to risk taking behaviour which may cause accidents. In larger quantities, alcohol slows down the body's functioning and can exacerbate fatigue.

In the past, the ease of identification of alcohol impairment has resulted in accidents which have involved both fatigue and alcohol being classified as alcohol-related only. In this study, Coroners' records in which the BAC of the driver is less than .10 and there is other evidence of fatigue were classified as fatigue-related. It should be noted that some other estimators of the contribution of fatigue to road accidents have classed fatigue as a contributing factor in all cases of alcohol impairment (e.g., Armour, Carter, Cinquegrana and Griffith, 1988).

2.3 STATE OF REGISTRATION

The Coroners' records described fatal accidents which occurred in Victoria, not fatal accidents involving Victorian-registered vehicles. Thus there are a number of vehicles registered interstate in the sample. There is a widely-held view that out of state registered vehicles (cars as well as trucks) may be over-involved in fatigue-related crashes because they are more likely to be on a long trip than locally registered vehicles.

Analysis of the Coroners' data showed that 90.5% of the vehicles for which information about state of registration was available were registered in Victoria. The most common out of state registrations were the neighbouring states of New South Wales (4.0%) and South Australia (2.9%).

The proportion of out of state registrations was greater for articulated vehicles than other vehicles. Of 101 articulated vehicles for which state of registration information was available, 19 (18.8%) were registered out of state. None of the rigid trucks were registered in another state.

2.4 OWNERSHIP AND TYPE OF VEHICLE

Ownership data were available for 239 vehicles involved in fatal acccidents involving trucks. Of these vehicles, 126 (52.7%) were driven by the owner and 113 (47.3%) by a person other than the owner.

The proportion of drivers who owned their vehicle differed markedly across vehicle types. Of the 82 cars for which ownership data was recorded, only 13 drivers did not own the vehicle. In 9 of 10 cases the rider of the motorcycle was the owner. In contrast, 69.8% of truck drivers trucks did not own the vehicle they were driving at the time of the accident. Thus, trucks were more likely to have been driven by a person other than the owner than were cars and motorcycles ($z=3.85$, $p<.05$). The proportions of articulated (73.9%) and rigid (61.7%) trucks which were non-owner-driven were similar.

In order to assess whether crash rates differed for owner-drivers and employee drivers, these accident frequencies need to be compared with the vehicle kilometres driven by the two types of drivers. The Survey of Trucking Operations conducted by the Bureau of Transport Economics (1986) presents data on the number of trucks driven by owner-drivers and others in the hire and reward sector and the average kilometres travelled. From these figures, it can be estimated that about 22% of the hire and reward truck kilometres involve owner-driven trucks. Within the margins of error associated with these estimates, this does not differ from the 30% of accident-involved trucks which were owner-driven.

2.5 HOURS SPENT DRIVING

It was hoped to derive a more accurate estimate of fatigue from analysis of hours spent driving and the nature of prior activities but, contrary to original expectations, the Coroners' records have proved a poor source of such information.

The variables sought from Coroners' records which were related to hours spent driving were trip departure point and time, destination and estimated time of arrival, number of rest breaks (greater than 30 minutes) during the trip, total driving time in the previous 24 hours, whether a rest period of five consecutive hours had been taken in the previous 24 hours and nature of pre-trip activity.

Unfortunately information on these variables was missing in a majority of cases. Trip departure point was available for only 126 of 372 vehicles. In 45 instances the trip was a local one. Fifteen vehicles had departed from interstate and the bulk of vehicles of the remaining vehicles had departed from country areas of Victoria.

Information about departure times was available for only 78 of 372 vehicles. In approximately 90% of these cases the vehicle had begun its journey on the previous day. Thus most of the vehicles for which information about departure times was available were on long trips at the time of the accident. This is suggestive of the involvement of fatigue in these crashes but the pattern may have resulted merely from the generally long-distance nature of truck traffic or from bias in reporting.

Destinations were available for only 70 vehicles. Fourteen of these vehicles had interstate destinations. There was a negligible amount (less than 10%) of information recorded about estimated times of arrival, number of rest breaks, total driving time, whether a five-hour rest period had been taken and nature of pre-trip activity.

2.6 ESTIMATES OF THE CONTRIBUTION OF FATIGUE

This section contains two estimates of the contribution of fatigue to fatal accidents involving trucks: an estimate based on the Coroners' judgements of the factors contributing to the accidents and an estimate derived from judgements made by the authors.

2.6.1 Coroners' judgements

Table 2 summarises the Coroners' judgements of the factors contributing to the fatal accidents involving trucks. In some accidents the Coroner did not identify a contributing factor, in some a single factor was identified, but Coroners identified several factors in most accidents. Thus the percentages in the table do not sum to 100%.

Fatigue was judged by Coroners to be present in 9.1% of accidents. This figure is likely to be an underestimate because Coroners rarely judged fatigue to be a contributing factor unless there was strong evidence that the driver was likely to have been asleep at the time of the accident.

The high proportion of accidents in which inattention was identified as a contributing factor supports the contention that the estimate of the involvement of fatigue based on the Coroners' judgement may be an underestimate. A state of reduced attention may have preceded falling asleep at the wheel. Therefore it is possible that fatigue may have been involved in some of the 25% of accidents in which inattention was judged to have been present. A recent review of driver inattention (Bishop, Madnick and Sussman, 1985) noted five physical and psychological states which are likely to degrade attention: drowsiness, physical fatigue, excess mental workload, intoxication due to alcohol, drugs or any other chemicals and "simple inattention" (daydreaming).

The number of detected cases of drug driving was small (3.2%), particularly in the light of earlier estimates of the proportion of truck drivers who drive under the influence of drugs (e.g., Nix-James, 1977; Lund, Preusser, Blomberg and Williams, 1987). Closer inspection of the data shows that drug driving was only detected in fatally injured car drivers. Testing for the presence of drugs occurred routinely only in the case of fatally injured drivers and there were only a small number of truck drivers killed. This led to a lack of information about drug taking by surviving truck drivers.

Table 2. Factors judged by Coroners to have contributed to fatal accidents involving trucks.

Contributing factor	Percentage of accidents
No factor identified	3.2
Inattention	25.3
Fatigue	**9.1**
Speed	22.0
Alcohol	14.0
Careless driving	9.1
Wrong side of road	15.1
Failure to yield right of way	11.8
Drug driving	3.2
Suicide	4.8
Other factors	23.7

Table 3 shows the estimated incidence of fatigue in car and truck drivers involved in fatal truck accidents. The incidence of fatigue of car, articulated vehicle and rigid truck drivers can be expressed as the number of fatigued drivers divided by the number of drivers of that type of vehicle. According to this method of analysis, car-driver fatigue was identified by the Coroner in 9.2% of accidents involving cars. Fatigue on the part of articulated vehicle drivers was identified in 5.1% of accidents involving these vehicles and fatigue was a contributing factor to 1.6% of accidents involving rigid vehicles. The difference in the estimates of fatigue between car drivers and articulated vehicle drivers is not statistically significant (z=1.2, p>.05)2. The number of drivers of rigid trucks who were judged to be fatigued is too small for statistical analysis.[*]

An alternative way of expressing the relative incidence of fatigue is to divide the number of fatigued drivers by the total number of fatal accidents involving trucks (186). This results in percentages of 5.4% for car drivers, 3.2% for articulated vehicle drivers and 0.5% for rigid vehicle drivers. The proportions of fatigued car and articulated vehicle drivers were not statistically different (z<1, p>.05).

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[*] Footnote 2. For statistical significance at the p<.05 level z must be greater than 1.65.

Table 3. Incidence of fatigue in car and truck drivers.

	Number fatigued	Percentage of drivers	Percentage of all accidents
Car drivers	10	9.2	5.4
Articulated vehicle			
drivers	6	5.1	3.2
Rigid truck drivers	1	1.6	0.5
Total	17		9.1

2.6.2 Authors' judgements

The criteria which were used in determining whether fatigue was likely to have contributed to an accident were

1. Coroner's statement that fatigue contributed to the accident
2. Long hours of work without rest breaks
3. Insufficient recovery periods
4. A long period of non-restful pretrip activity
5. Evidence of falling asleep at the wheel, e.g., making no attempt to negotiate a curve or failure to apply the brakes.

When these criteria were applied, fatigue was judged to have contributed to 37 of the sample of 186 fatal accidents involving trucks (19.9%). Table 4 summarises the involvement of fatigue of car, rigid truck and articulated vehicle drivers in fatal truck accidents. Fatigue on the part of the car driver was identified in 12.4% of all of the fatal accidents involving trucks, and 21.1% of those fatal truck accidents in which cars were involved. Drivers of articulated vehicles were judged likely to have been fatigued in 6.5% of all of the accidents and 10.2% of the accidents which involved articulated vehicles. Drivers of rigid trucks were fatigued in only two accidents, 1.1% of the total sample and 3.2% of the accidents involving rigid trucks. Statistical analyses showed that the contribution of car-driver fatigue was greater than fatigue of articulated vehicle drivers regardless of whether the proportion of accidents involving that vehicle type ($z=2.3$, $p<.05$) or the proportion of the entire sample ($z=1.96$, $p<.05$) was considered. The number of rigid truck accidents judged to be fatigue-related was too small to allow statistical comparisons.

The locations of accidents judged to have been fatigue-related are presented in Appendix Three.

Table 4 Estimates of the contribution of fatigue based on the authors' judgements.

	Number fatigued	Percentage of drivers	Percentage of all accidents
Car drivers	23	21.1	12.4
Articulated vehicle			
drivers	12	10.2	6.5
Rigid truck drivers	2	3.2	1.1
Total	37		19.9

2.6.3 Assessment of the estimates of fatigue

The criteria used by the authors in judging whether fatigue was a contributing factor to an accident were similar to those used by Armour et al. (1988). They concluded that it was probable that the driver had fallen asleep in 27% of the cases investigated. This figure is similar to but lower than the overall estimate of 19.9%. The estimates reported here may be lower than those because the authors did not classify an accident as fatigue-related if any driver's BAC was greater than .10. Armour et al. judged these accidents to be fatigue-related.

Additionally, it should be noted that for ethical reasons, Armour et al. did not send questionnaires to persons who had been involved in fatal or serious accidents. They studied only single-vehicle rural accidents, a sample which might be expected to have a larger proportion of fatigue-related accidents than a mixture of accident types. Thus, their sample of accidents is quite a different one from Victorian fatal accidents involving trucks.

The estimates of the contribution of fatigue to accidents from this study cannot be directly compared with the findings of the South Australian rural in-depth study (Ryan, Wright, Hinrichs and McLean, 1988). In that study, 31.4% of all accident-involved drivers and 41.7% of accident-involved truck drivers responded that they had felt slightly, moderately or very fatigued at the time of the accident. They did not report any other evidence that fatigue may have contributed to the accident.

2.7 MECHANICAL DEFECTS

As mechanical defects are reported in Coroners' records and could be readily collected, the opportunity was taken to include this matter in the report.

Truck systems "particularly engine and brakes work much closer to their design limit in normal operation than a passenger car. This means that a high standard of servicing of brakes, suspension, steering and tyres is essential to maintain safe operation" (NRMA, 1986, p. 35). Thus it is likely that the presence of mechanical defects in trucks could play a significant role in truck accidents.

A number of studies of the role of truck mechanical defects in accidents have been conducted. In a study of Queensland road accidents involving semi-trailers, McDonald and McDonald (1983) found that approximately ten per cent of accident reports indicated mechanical failures. These included failures of trailer couplings, brakes, steering, tyres, suspension and lights.

McDonald and McDonald also reported an investigation of mechanical defects in Telecom trucks by Vidler. They comment that whilst these units are likely to be among the best maintained on the road, some showed unsatisfactory braking performance. Telecom has found it necessary to modify some of their trucks and trailers to achieve satisfactory braking.

The Queensland Road Safety Research Group (1986) reports that mechanical failures were present in 32.3% of single-vehicle semi-trailer accidents. Faulty brakes accounted for 30.2% of faults, followed by loose trailers (21.6%). For multi-vehicle accidents, 3.5% were due to mechanical defects in semi-trailers.

A study of Victorian accidents (Cowley, 1978) showed that vehicle defects were reported by Police as contributing to the accident in 3.5% of single-car accidents and 6.5% of single-truck accidents. This difference is statistically significant. The same trend was present for multiple-vehicle accidents.

Dunlap and O'Day (1975) investigated the incidence of tyre failure in large trucks and its contribution to accidents. They cite earlier reports by the Bureau of Motor Carrier Safety which "indicate that accidents resulting from truck tire failures constitute about 0.82% of all truck accidents and 0.87% of all fatalities in truck accidents" (Dunlap and O'Day, 1975, p. 1). Their study suggested that the frequency of tyre failure and the severity of the resulting consequences depend upon whether truck travel on a variety of roads or only on freeway standard roads is considered.

Analysis of data for the State of Texas (all road conditions) showed that 0.86% of all truck accidents were reported as having been caused by tyre failure and that tyre failure accidents were somewhat more severe than other truck accidents. On the Ohio, Indiana and Pennsylvania Turnpikes 4 to 5% of truck accidents involved tyre failure but the severity of these accidents was lower than that of truck accidents as a whole.

Their case studies of two trucking companies suggested why different results were found for turnpike and general operation. The operators applied different maintenance standards to vehicles travelling locally and intercity. On vehicles travelling long distances retreads were not used on prime mover axles, tyres were replaced when tread depth reached between 6/ and 8/32 of an inch and tyres on each axle were carefully matched. Less stringent criteria were applied to vehicles being used for local work.

Dunlap and O'Day cite a study which found in car accidents that tyre failure was frequently reported erroneously as a contributing factor. They warn that accident reports for trucks may show the same problem.

A recent US study found defective equipment in 77% of semi-trailers involved in crashes but in only 66% of semi-trailers not involved in crashes (Jones and Stein, 1987).

2.7.1 Mechanical defects from Coroner's records

From the Coroners' records information about defects was available for 242 vehicles. No defects were reported in 208 (86.0%) of these vehicles. Nine vehicles had defective brakes, two had defective steering and 16 were classed as having defective tyres. Defects were found in the lighting systems of three vehicles and in other systems of four vehicles.

Results of inspections for mechanical defects were reported for 98 articulated and 40 rigid trucks. There was no statistically significant difference between the proportions of defects in articulated vehicles (10.2%) and rigid trucks (17.5%, z=1.18, p>.05). Table 5 shows that tyre defects were the most common type of mechanical defect for both articulated and rigid vehicles.

The foregoing figures referred to the frequency of identifiable mechanical defects in accident-involved vehicles. Vehicle inspectors' judgements of whether the identified defects were responsible for the accident were available in some cases. Defects (in cars, trucks, or other vehicles) were considered by the Coroner to have been a proabable cause in eight crashes (3.4% of the cases for which data was available) and a possible cause in another eight crashes.

For trucks only it was considered that defects were a probable cause in 5 crashes (of the 133 crashes for which data were available) and a possible cause in another 4 crashes. Caution should be exercised in drawing conclusions from these small numbers but they are an indication that mechanical defects may be more important in trucks than cars and underline the need for more definitive information about this matter.

It is also important to bear in mind that in many cases vehicles, particularly cars, were very badly damaged. This reduced the likelihood that subsequent inspection could detect vehicle defects present prior to the crash.

Table 5. Truck mechanical defects recorded by Coroners.

Vehicle system	Proportion of inspected vehicles defective	
	Articulated vehicles	Rigid trucks
Brakes	2/98	0/40
Steering	1/98	1/40
Tyres	4/98	5/40
Lighting	1/98	1/40
Other	2/98	0/40

Owner-drivers and mechanical defects. Concern has been expressed that trucks driven by owner-drivers may be less well maintained than fleet trucks and that this may increase their accident risk.

The absolute numbers of defects reported is small when disaggregated by type of vehicle and ownership. For articulated vehicles, five of nineteen owner-driven trucks were identified as having a defect (26.3%) and three of 58 trucks known to be driven by another person were defective (5.1%). While these results are in accord with the concern about maintenance neglect by owner-drivers, the results are based on such a small number of defects that such an interpretation may be premature.

The pattern for rigid trucks seems to differ somewhat. Two of twelve owner-driven trucks showed defects (16.7%) as did two of 18 trucks driven by other persons (11.1%). However, these numbers are really too small to allow any conclusions to be reached.

2.8 CONCLUSIONS FROM ANALYSES OF CORONERS' RECORDS

The analyses of state of registration and ownership of trucks involved in fatal crashes showed that 18.8% of articulated vehicles but no rigid trucks were registered in another state and about 70% of trucks were non-owner-driven. The Coroners' reports yielded sparse information on hours spent driving. In approximately 90% of cases for which data was available, the driver had begun his or her journey on the previous day. This is suggestive of the involvement of fatigue in these crashes but the pattern may have resulted from the generally long-distance nature of truck traffic or from bias in reporting.

To interpret the results of the analyses of vehicle ownership, state of registration and hours spent driving, it would be necessary to compare the values derived from the Coroners' records with values from non-accident-involved trucks.

Analysis of the Coroners' records resulted in estimates of the involvement of fatigue in fatal truck accidents varying from 9.1% (using the Coroners' judgements) to 19.9% (derived from the authors' judgements). The estimate based on the Coroners' judgement is likely to represent the lower bound of the role of fatigue in fatal accidents involving trucks. Nevertheless, even if the lower bound set by the Coroners' judgements is accepted, the problem of driver fatigue in truck accidents is still of sufficient magnitude to warrant further research.

An estimate of the cost of fatigue-related truck accidents can be made by using information derived from the data base of Police-reported accidents maintained by the Road Traffic Authority and cost estimates for road accidents (Bureau of Transport and Communications Economics, 1988). The Coroners' estimate of 9.1% corresponds to 20.8 fatal accidents in the 1984-6 period covered. Analysis of the RTA data showed that, on average, 1.3 persons died in each fatal truck accident, and 0.6 persons were hospitalised and 0.8 persons required medical attention in each casualty truck accident. The assumption that the ratio of casualty to fatal accidents is the same for fatigue-related accidents as for truck accidents in general is likely to result in an underestimate of the cost of fatigue-related accidents, based on evidence of increased severity of fatigue-related accidents. However, if this assumption is made, the 21 fatigue-related fatal accidents in the Coroners estimate can be said to represent, in addition, another 255 casualty accidents.

Based on BTCE estimates, the cost of these accidents is approximately $6,000,000 per year in Victoria. This value is conservative since it assumes vehicle costs are the same in truck accidents as in non-truck accidents. It is likely that factors such as loss of load and the large cost of trucks mean that vehicle costs are greater in truck accidents.

If the cost calculations are based on the 37 accidents identified by the authors as fatigue-related, the cost becomes approximately $13,100,000 per year.

Neither estimate of the cost of fatigue-related truck accidents includes costs resulting from property-damage only accidents.

One of the interesting findings from the examination of Coroners' reports was that fatigue of car drivers was strongly involved in fatal truck accidents. This finding should be treated as a tentative one, since there may have been selective reporting in the Coroners' records, lowering the estimates of fatigue in accident-involved drivers. Truck drivers more often survived the accident to provide witness information, which may have biassed the available evidence.

Care also needs to be taken in the interpretation of this finding because it cannot be assumed that the contribution of car driver fatigue to accidents not involving trucks would be the same. There is a need for an examination of Coroners' records of fatal accidents involving cars to investigate the meaningfulness of the car driver fatigue findings of this study.

Nevertheless, the significant role of car driver fatigue in fatal truck accidents suggests that fatigue countermeasures should be targeted at both types of road user and that evaluation of the benefit-cost ratios of countermeasures should incorporate effects on both cars and trucks.

3 ACCIDENT-TIME OF DAY ANALYSES

The purpose of these analyses was to derive an indirect estimate of the involvement of fatigue in Victorian truck accidents by determining whether accident risks are higher at night, when drivers are more likely to fall asleep at the wheel. While the analyses provide a measure of the correlation between accident risk and time of day, they cannot show that fatigue caused any increased night-time accident risk.

The first two sections of this chapter present a review of research linking fatigue and night-time accidents and an outline of the methodology used in the analyses. The process of adjustment of accident frequencies for exposure is explained and the results of the exposure-adjusted analysis are then presented.

3.1 FATIGUE AND NIGHT-TIME ACCIDENTS

Overseas studies have shown that most accidents which result from drivers falling asleep at the wheel occur between the hours of midnight and six a.m. (Hamelin, 1980, cited in McDonald, 1981; Harris, 1977; Lisper, Eriksson, Fagerstrom and Lindholm, 1979; Prokop and Prokop, 1955, cited in Langlois, Smolensky, Hsi and Weir, 1985). Analysis of the temporal pattern of truck accidents compared with traffic volumes provides an indirect estimate of the magnitude of the Victorian truck driver fatigue problem.

Robinson, Kihlberg and Garrett (1969) reported data on 970 occupants of 680 trucks involved in injury-producing accidents in the United States. They found that cars and utilities had the majority of their accidents in the late afternoon whilst semi-trailer accidents were most frequent in the early morning and early afternoon.

There have been few Australian studies of accidents as a function of time of day and traffic flow. Foldvary (1975) presents some Queensland data but they were collected in 1964 and so are likely to be out-dated. His data show that when corrected for exposure, accident rates are highest from midnight to four a.m. Unfortunately he does not report his findings disaggregated by type of vehicle.

The relationship between time of day and frequency of semi-trailer accidents reported to the Queensland Police was analysed by McDonald and McDonald (1983). They divided each day into two-hour periods and found different diurnal trends for single- and multiple-vehicle accidents. Single-vehicle accidents were quite evenly distributed throughout the day whereas the pattern of multiple-vehicle accidents peaked in the mid-morning and mid-afternoon.

Vulcan (1987) reports a study undertaken by the Victorian Road Traffic Authority of accidents in which at least one person was killed or admitted to hospital between 1977 and 1984. In the metropolitan area most crashes occurred between 6 a.m. and 6 p.m. for articulated vehicles (74%), rigid trucks (84%) and buses (66%, 8 a.m. to 10 a.m., noon to 6 p.m.). However, outside the metropolitan area the crash rate for articulated vehicles showed little diurnal pattern whilst rigid trucks and buses retained the metropolitan pattern. If one makes the not unreasonable assumption that traffic flow was less during night time hours, then adjusting for exposure would show that night time crashes (likely to involve fatigue) were more likely for articulated vehicles than rigid trucks and buses.

In a recent Victorian study Chow (1987) computed correlations between frequency of truck accidents along highway corridors and total and commercial traffic flow data.

His analysis demonstrated that "65% of the casualty accidents occurred between the hours of 7am to 7pm, as against 72% of the traffic volume (limited RCA traffic count data for the Western and Hume). Accidents are at a maximum during normal business hours (9am to 5pm), with the lowest level of accidents at 3am" (p. 6).

After adjustment for exposure the results were not the same for all Victorian highways. There seemed to be elevated night-time risks, indicative of driver fatigue, in municipalities bordering the Hume Highway.

> Traffic flow data [for the Hume Highway] shows that between the hours of 7pm and 7am traffic flow volume for all traffic accounted for approximately 27% of total traffic flow, but 52% of truck accidents occur in the same period. Therefore night time crash involvement is substantially higher than day time rates. In addition, whilst accidents by time of day are relatively constant, data reveals that the higest level of accidents are between the hours of 6pm to 8pm and the lowest are between the hours of 8am to 10am. Further, considering the low truck flows, the 4am to 6am peak also indicates an area for concern. (Chow, 1987, p. 7)

In contrast, accidents in municipalities bordering the Calder Highway and Western Highways were proportional to traffic volumes for the same periods. That is, night-time accidents were not over-represented.

Unlike Chow's work, the current study analysed accidents occurring on highways only, not all neighbouring municipalities. This should result in the traffic volume estimates reflecting more precisely the exposure of the accident-involved vehicles. More details of the conduct of the analysis are given in the following section.

3.2 RESEARCH STRATEGY

If the distribution of factors involved in accident causation was even throughout the day, then the proportion of accidents in a given time period would be equal to the the proportion of daily traffic flow that occurred in that time period. In other words, exposure would explain accident distributions, resulting in accident risks that were constant across the day. However, factors such as fatigue and alcohol (McDermott and Hughes, 1983) are involved in more night-time than day-time accidents. This research calculates risk values for each two-hour period to investigate whether any evidence can be found of increased night-time driving risks.

This research strategy is a correlational approach, it can only produce evidence of elevated night-time risk to which fatigue is likely to have contributed. It is possible that an elevated night-time risk could result from the population of night-time drivers differing on some other dimension than fatigue. For instance, these trucks might drive faster or be more poorly maintained.

It should be noted that the accident-time of day analyses reported here may underestimate the role of fatigue in truck accidents. If truck drivers suffer from chronic fatigue their likelihood of having an accident may be more evenly distributed throughout the day. Drivers with chronic fatigue may fall asleep at the wheel during daytime whilst those with acute fatigue may be less likely to do so. The distinction between chronic and acute fatigue is discussed by Cameron (1973) and Nairn (1987).

3.3 METHODOLOGY

In this study the diurnal pattern of accidents which occurred on highways were adjusted for the diurnal flow pattern of that type of vehicle. The total number of truck accidents (articulated plus rigid) in each time period was adjusted for the total number of trucks counted during that same period of the day.

The analysis was confined to accidents which occurred on highways. This made the adjustment for exposure more valid by ensuring that the population of exposed vehicles was similar to the population of accident-involved vehicles. An unfortunate effect of confining the data to highway accidents was that this reduced the numbers of accidents available for analysis. While there were about 1500 rural accidents which occurred during the period 1982-86, only about 500 of these occurred on the five highways which were studied. This reduced the reliability of the risk estimates.

Statistical analyses of the risk estimates were not conducted.

Results are presented separately for total trucks (articulated plus rigid), articulated vehicles and rigid trucks for each highway. It was decided that patterns of risk estimates might differ among highways and that a state aggregate would not be meaningful. In addition, there are difficulties in achieving a satisfactory method of weighting the data to produce a state average.

Descriptions of the data sources used and the method of adjusting for exposure follow.

3.3.1 Data sources

The accidents analysed in this report were drawn from the data base of Police-reported accidents maintained by the Road Traffic Authority (RTA). The accidents occurred in the years 1982-86 and involved at least one articulated vehicle or rigid truck. The accidents resulted in casualties or fatalities. The analysis was restricted to accidents which occurred outside the Melbourne metropolitan area.

The Road Construction Authority (RCA) provided vehicle counts from a requested sample of permanent recording stations. These counts gave the total number of vehicles, number of vehicles under 5.5m (labelled cars), number of vehicles between 5.5m and 12m (labelled rigid trucks) and the number of vehicles over 12m (labelled articulated trucks) for each lane in each hour of each day at each station.

The vehicle counts covered a four-week period in October-November 1988. It was assumed that although traffic volumes may have differed between the periods covered by the accident and vehicle count data, it was unlikely that the distribution of traffic flow as a function of time of day had changed markedly.

Preliminary analyses showed that accident frequency was not the same for each day of the week. Since it is likely that exposure varies in this way also, traffic volumes for each day of four weeks were analysed. This allowed equal representation of each day of the week and the four examples of each day reduced the effect of random fluctuations.

The only exception to the foregoing paragraph occurred in the case of Station 104 on the Calder Highway. Due to an equipment malfunction data were not available for the entire four week period and so three weeks' data were analysed instead.

Diurnal patterns of truck accidents on the Hume, Princes Highway East, Princes Highway West, Calder, Murray Valley and Western Highways were compared with truck flows from counting stations on those highways. The available information was vehicle counts from permanent recording stations operated by the RCA. It was decided to assign accidents to vehicle counting stations. This involves the assumption that diurnal patterns of traffic flow were the same at the accident site and the vehicle counting station.

It was necessary to aggregate accident data for each highway to obtain useful sample sizes and this probably resulted in some violations of the assumption that the diurnal pattern of traffic flow was the same at the accident site and the counting station. Widely separated locations may have different diurnal traffic volume patterns, particularly if a "wave" passes along a highway.

Traffic volume data were analysed from one vehicle counting station per highway. Along most highways there was more than one counting station but the restriction to one station was used to reduce the quantity of vehicle counts to be analysed and because it was unclear as to the weighting procedure which would be necessary to combine data from multiple counting stations.

Disaggregation of accidents and traffic volumes by direction of travel would have allowed the effect of trip length to be studied but there was not sufficient accident or traffic volume data to allow this analysis to be performed.

Only stations which could provide traffic counts disaggregated by vehicle length were considered for analysis. Without such disaggregation, it would only be possible to compare truck accident frequency with total traffic volume. This is a comparison which was considered unlikely to be helpful because of contamination of the diurnal truck flow pattern by cars which it was judged likely to have a differing pattern.

The locations of the counting stations used are listed in Appendix 4.

3.3.2 Analysis procedure

A number of methods of measuring and adjusting for exposure exist. These are outlined in Appendix 5. The steps used in adjusting accident frequency for exposure in this study are detailed in this section.

For each highway examined, the percentage of accidents which occurred in each two-hour period (beginning at midnight) was computed for articulated vehicles, for rigid trucks and for all trucks (articulated plus rigid). The accident frequencies for each highway for each two-hour period are presented in Appendix 6.

From the vehicle counts the average daily volume of articulated vehicles, rigid trucks and all trucks (articulated plus rigid) was computed for each station. The count entered into the analysis was the average of flows in the channels (lanes or directions). The volume in each two-hour period was divided by this number to give the percentage of daily flow that occurred in each two-hour period. The volumes of each vehicle type for each two-hour period are presented in Appendix 6.

The final step in the analyses was the division, for each two-hour period, of the percentage of accidents by the percentage of vehicle flow. This allowed risk estimates to be compared for different times of the day for articulated, rigid and all trucks in each region. These risk estimates are listed in Appendix 6.

A risk estimate of 1.00 for a particular region and two-hour period means that the proportion of truck accidents which occurred during that time was equivalent to the proportion of trucks travelling during that time. Values below 1.00 indicate that is a lower risk time of the day and vice versa.

Risk estimates can be spurious if numbers of accidents or traffic volumes are low in any two-hour period. A small change in either flow or accident frequency could produce a large change in the unstable risk estimate.

3.4 ACCIDENT RISKS BY TIME OF DAY

3.4.1 All trucks

The risk estimates for all trucks (see Figure 1) should be more reliable than those for articulated vehicles or rigid trucks because they are based on more accidents and greater vehicle flows. However, if differences in patterns of risks for articulated and rigid trucks exist, the estimates for the combined sample may not be representative of either type of truck.

When risk values for all trucks are considered, the highest risk estimates occur during night-time for each highway. In addition, there is a general trend for risk estimates to be higher during the night than during the day.

For the Princes Highway East and the Prince Highway West, the highest risk estimate was for the 2200 to 2400 period . The highest value occurred during the 2400 to 200 period for the Calder, Hume and Murray Valley Highways. For the Western Highway, the highest risk estimates related to the periods from 400 to 600 and 600 to 800 hours.

3.4.2 Articulated vehicles

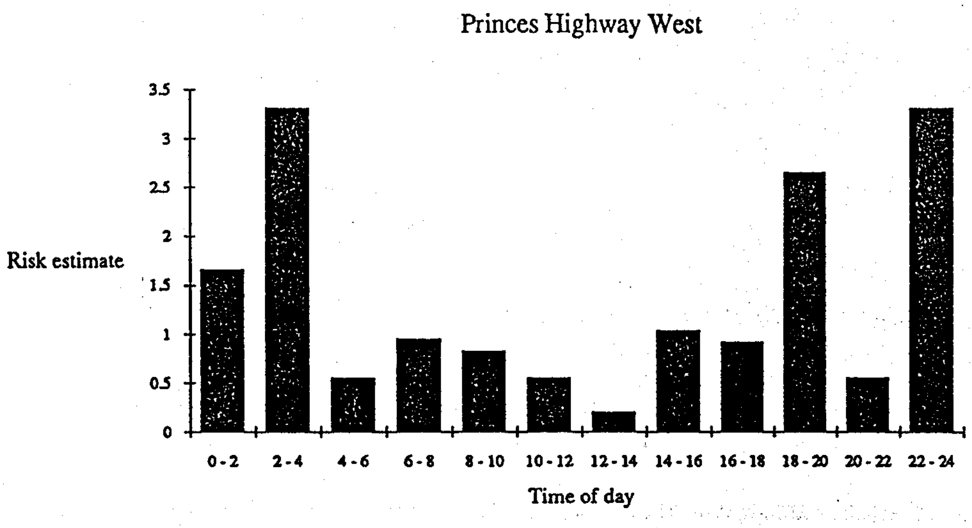
The risk estimates for articulated vehicles are presented in Figure 2. These estimates are likely to be less reliable than those for all trucks because the number of accidents upon which the analysis is based is smaller and the traffic counts are also lower. For some highways there were no accidents in some two-hour time periods resulting in a meaningless risk estimate of zero. This occurred for four two-hour periods for the Calder Highway and for one two-hour period for the Princes Highway West.

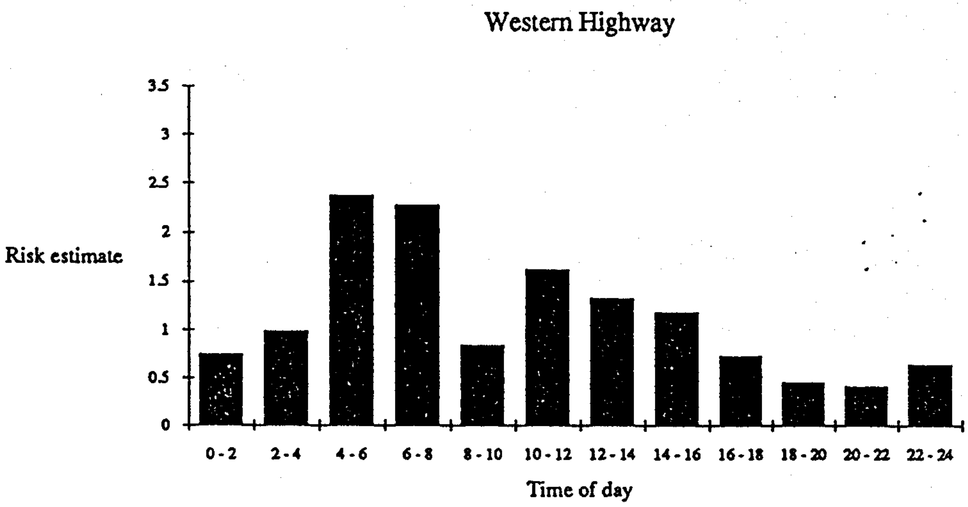
The times of maximum risk were more widely distributed for articulated vehicles than for all trucks. The highest risk estimate corresponded to 2400 to 200 hours for the Clder, Hume and Murray Valley Highways, although the Murray Valley Highway had a second peak between 400 and 600 hours. Peak risk estimates occurred in the 600 to 800 time period for the Western Highway and the Princes Highway East. For the Princes Highway West the period of maximum risk was from 1800 to 2000 although high risk estimates were present for the 2200 to 2400 and the 200 to 400 time periods.

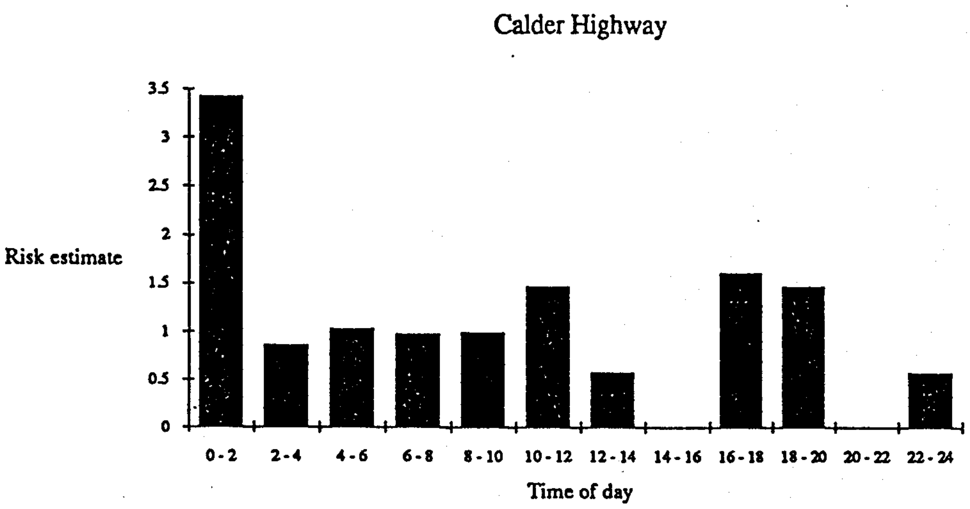
3.4.3 Rigid trucks

The risk estimates for rigid trucks are presented in Figure 3. Caution should be exercised in their interpretation because of the limited number of accidents and the small traffic flows from which they were derived. For each highway with the exception of the Princes Highway East, there were periods in which absence of accidents or rigid trucks precluded the estimation of risk.

The time periods of highest risk were widely spread. The highest risk values corresponded to the 2400 to 200 time period for the Princes Highway East, the 400 to 600 period for the Calder Highway, the 1400 to 1600 time period for the Western Highway, the 2000 to 2200 period for the Murray Valley Highway and the 2200 to 2400 time period for both the Princes Highway West and the Hume Highway.


Princes Highway West


Western Highway


Calder Highway

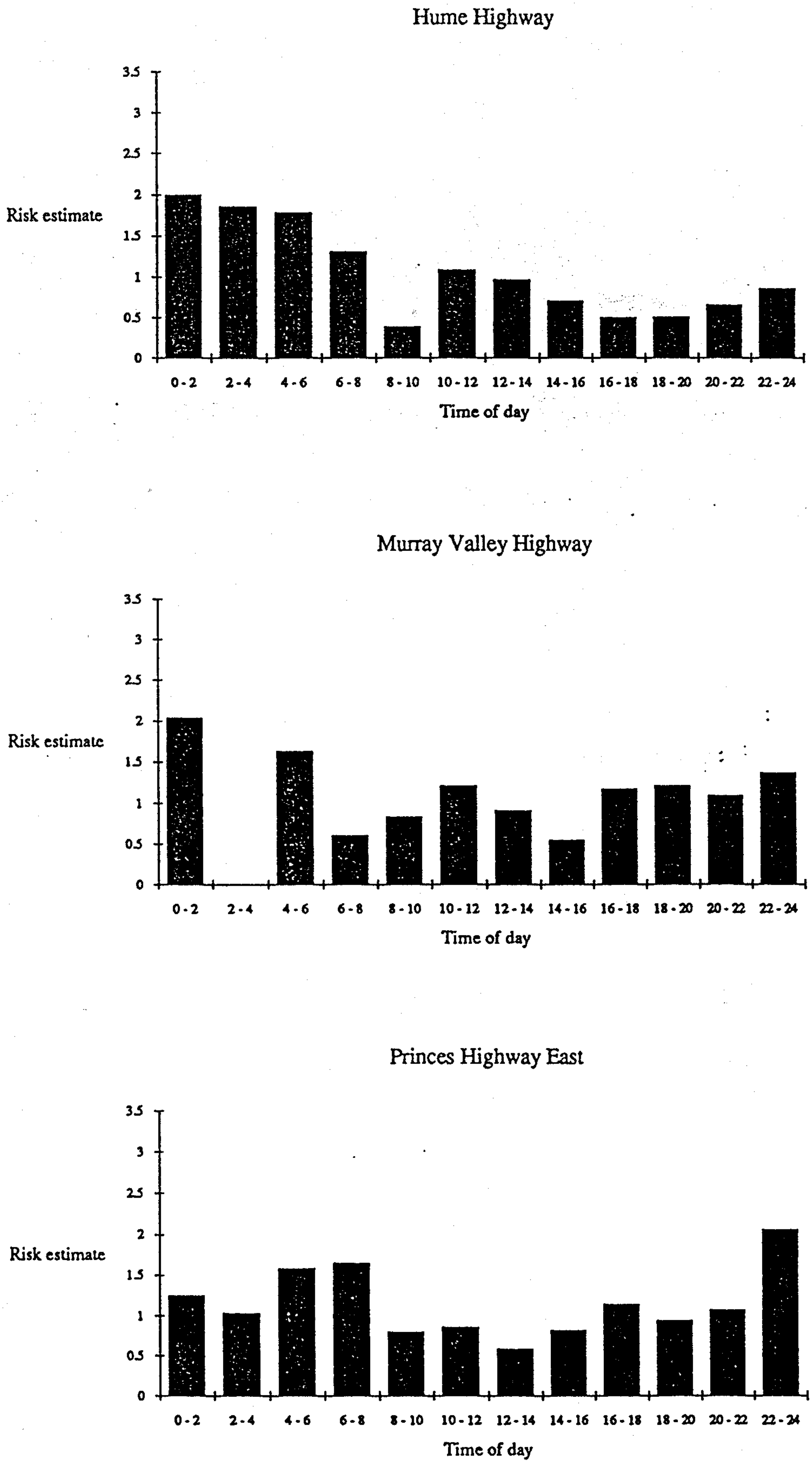
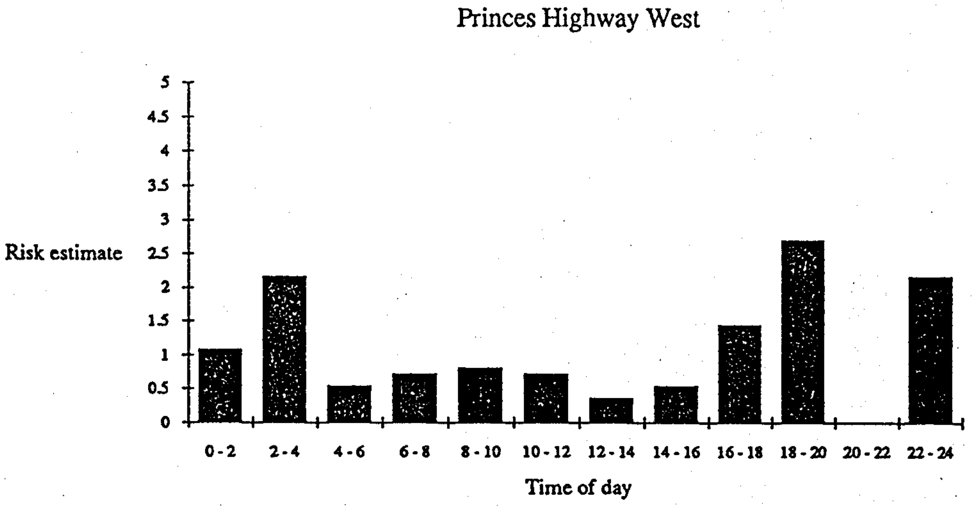
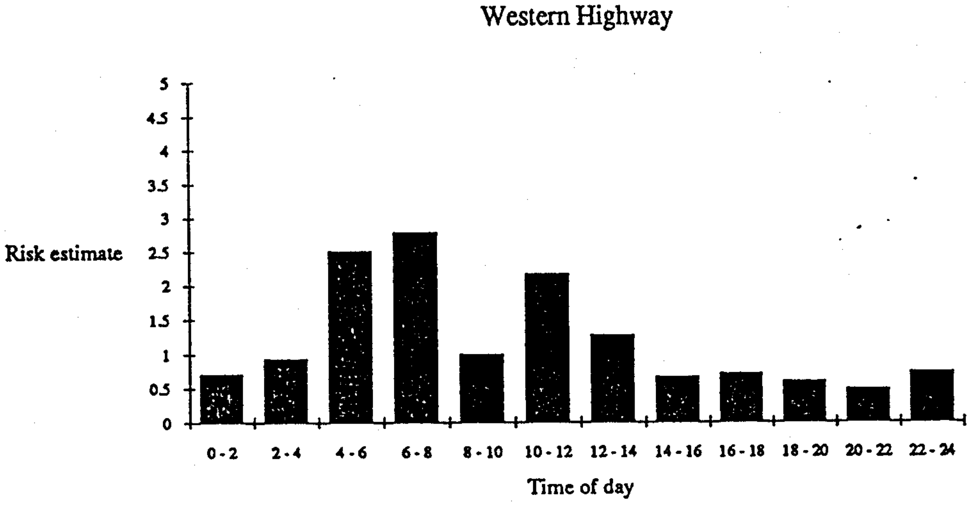


Figure 1. Risk estimates for all trucks (articulated vehicles plus rigid trucks) per two-hour period.


Princes Highway West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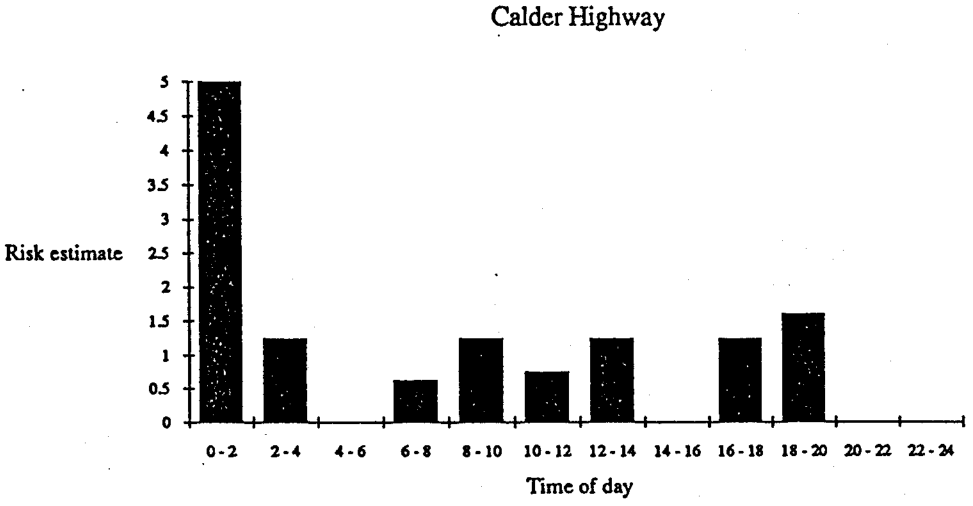

Calder Highway

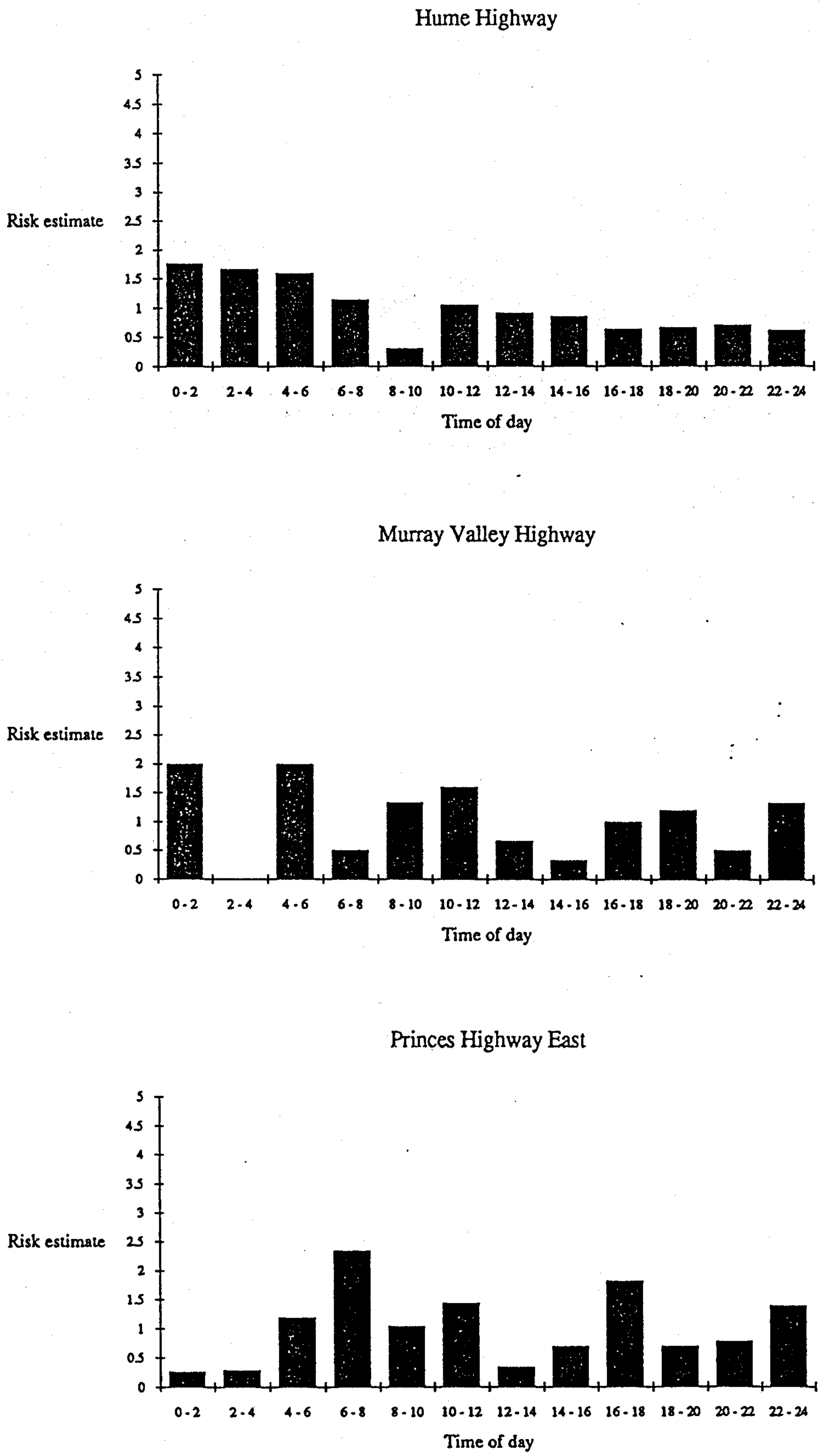
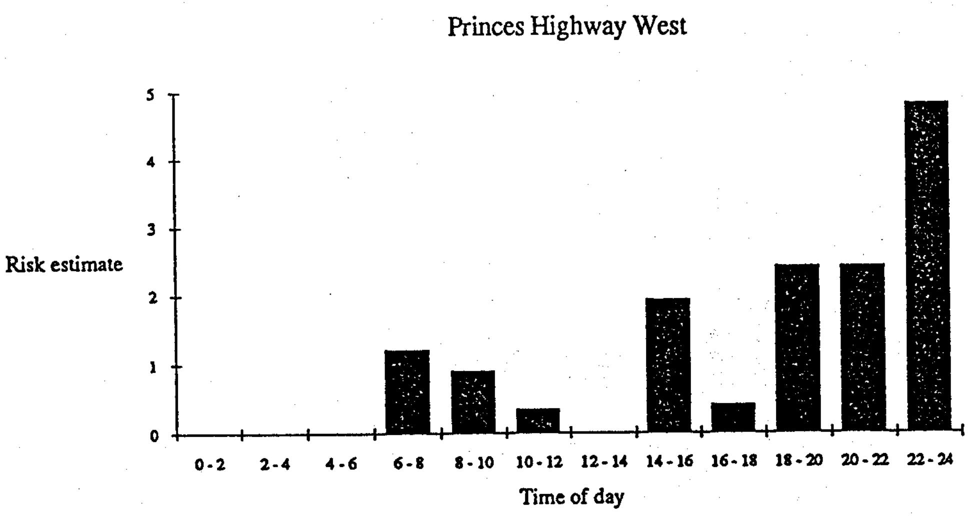
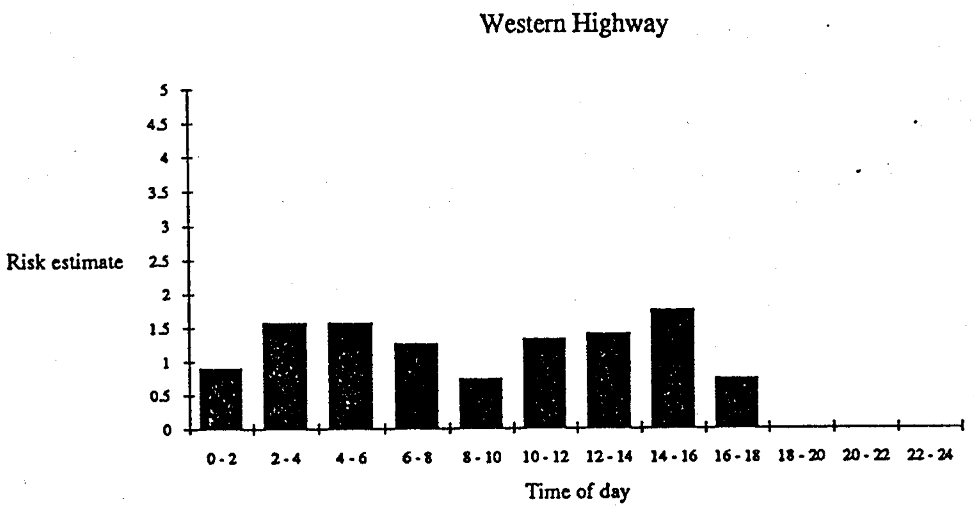
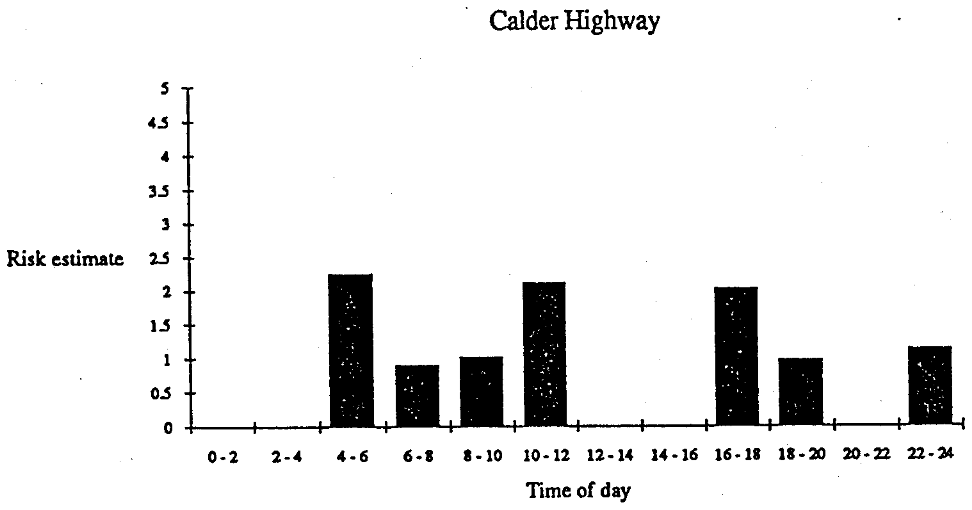
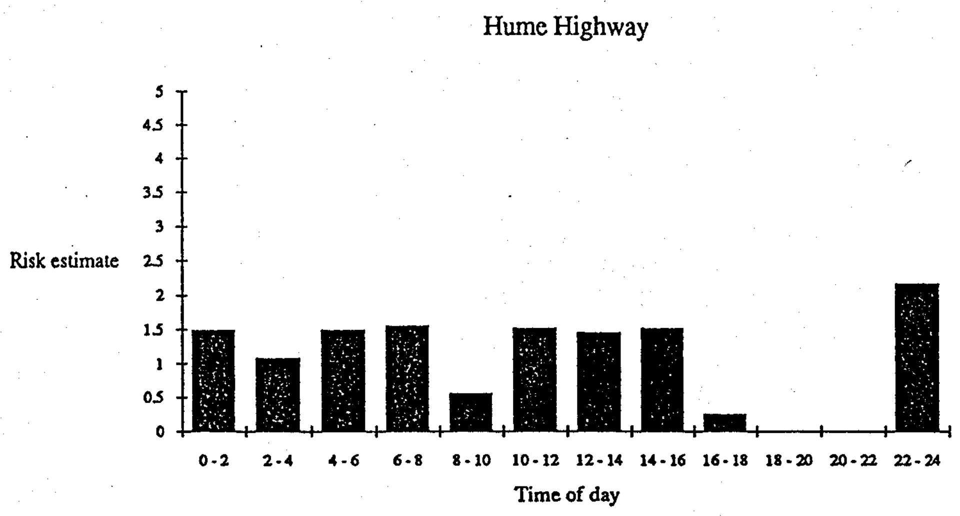


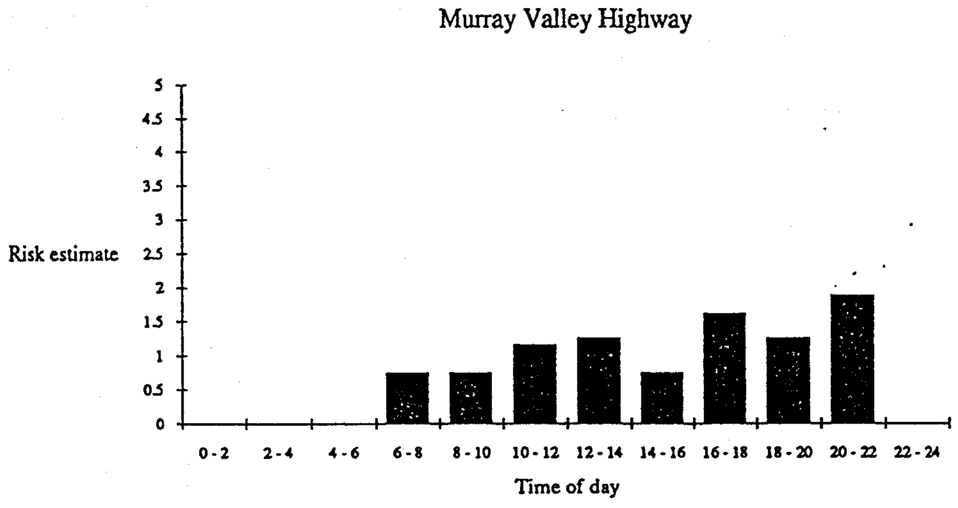
Figure 2. Risk estimates for articulated vehicles for each two-hour period.


Princes Highway West


Western Highway


Calder Highway





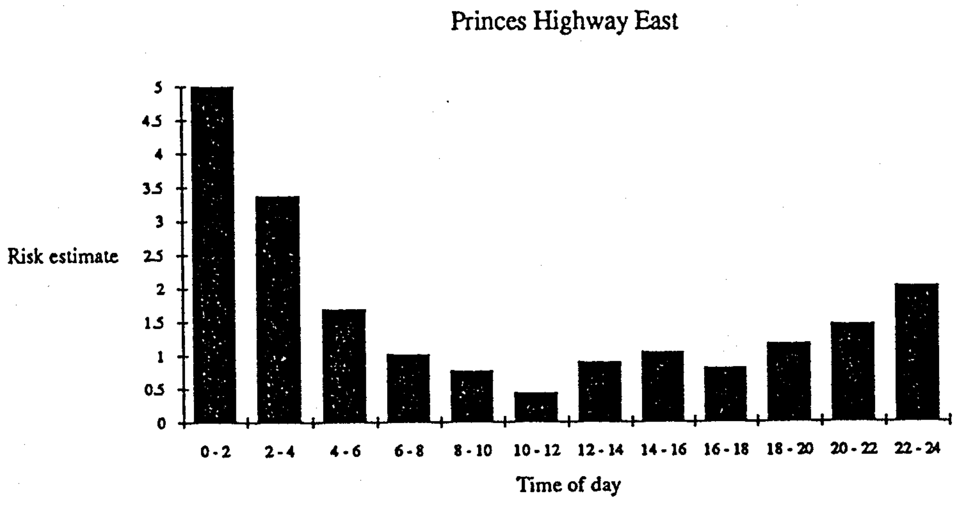


Figure 3. Risk estimates for rigid vehicles for each two-hour period.

3.5 CONCLUSIONS FROM TIME OF DAY ANALYSES

Accident risks were higher at night than during the day for articulated vehicles. Driver fatigue is one of the possible factors underlying this pattern of elevated risk.

The results of the analyses were less clear for rigid trucks. There were few accidents and few rigid trucks counted during the night on most highways, resulting in an inability to calculated risk estimates for some time periods. Nevertheless, it can be said that the paucity of night-time accidents suggests that fatigue is less of a problem for drivers of rigid trucks than for drivers of articulated vehicles.

4 IN-VEHICLE FATIGUE COUNTERMEASURES

The purpose of this review is to select in-vehicle fatigue countermeasures for laboratory testing in the second stage of the project.

Fatigue countermeasures of a different sort, those related to education, are described in a separate volume entitled *Information for Development of an Educational Program to Reduce Fatigue-Related Truck Accidents.*

4.1 CLASSES OF COUNTERMEASURES

There are a number of classes of fatigue countermeasures presently available. These include education (training and publicity), limitation of hours of work, stipulation of rest periods, enforcement, road design, fatigue monitors, stimulants and auditory input. A recent review conducted for the Federal Office of Road Safety (Haworth, Triggs and Grey, 1988) concluded that education and in-vehicle solutions (devices and driver strategies) were the countermeasures most likely to be successful in the short term.

In-vehicle fatigue countermeasures include devices which maintain and/or monitor driver alertness. A review of devices utilizing these principles is presented, and their potential effectiveness is assessed. Driver strategies to maintain alertness are also in-vehicle fatigue countermeasures and they are addressed in the latter part of this report.

4.1.1 In-vehicle versus on-road countermeasures

Devices used to counter the onset of fatigue and/or alert the driver can be situated either within the vehicle or on the road. There are different advantages and problems associated with on-road versus in-vehicle countermeasures.

In-vehicle devices have the potential to allow rapid detection of any sudden effect, (e.g., eye closure, head-nodding) and could alert drivers when such behaviours reached a predetermined criterion value.

In-vehicle devices can be operative all the time that the vehicle is driven but need to be fitted to every vehicle. In comparison, treating the whole of the road system with fatigue-alerting devices (e.g., rumble strips) could be prohibitively expensive so treatment would probably need to be restricted to the higher accident frequency areas.

There is evidence of the effectiveness of on-road countermeasures, however. In overseas studies a number of pavement treatments have been shown to be effective in alerting the dozing driver. The best known are rumble strips which are grooves or rough patches of pavement. Tyres running on the rumble strip transmit an audible and vibratory signal to the driver.

On a 23 mile section of California's Interstate 15 across the Mojave Desert, a continuous series of parallel grooves was pressed into the asphalt on the shoulder while it was still hot (see Figure 4). Application of the rumble strips resulted in a 49 per cent reduction in run-off-road accidents and a reduction in total accidents of 19 per cent during the first seven years (TR News, 1988). This corresponds to accident savings of $6.15 million (US) for an initial outlay of about $23,000 (US) or about $1,000 (US) per mile.

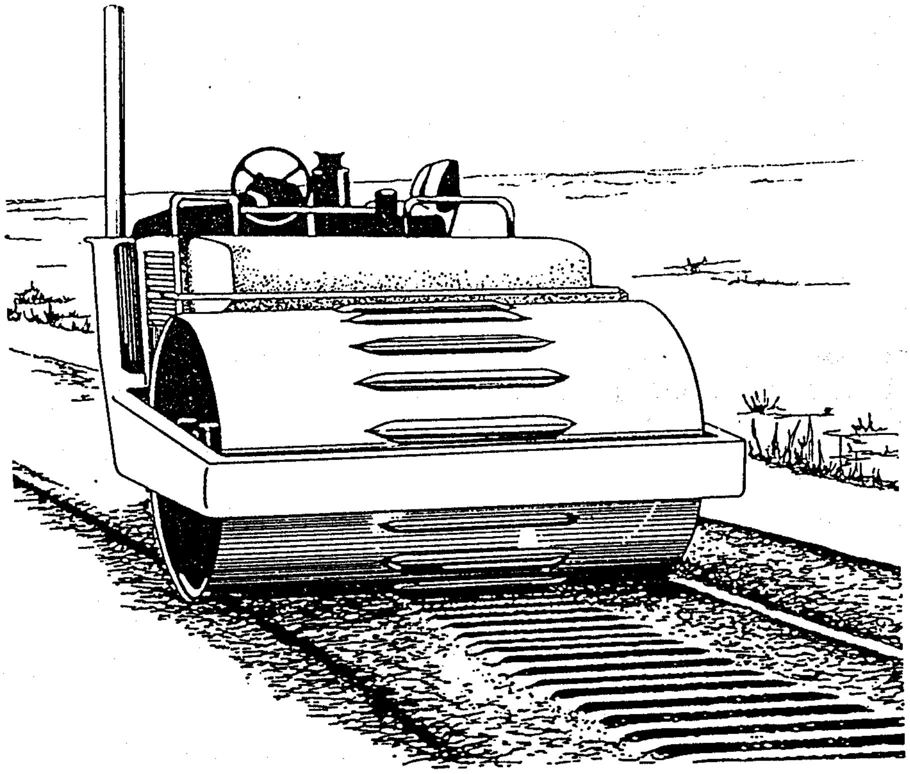


Figure 4. Application of a rumble strip to a section of the Interstate 15 in California.

Another pavement treatment which is effective as a fatigue countermeasure is that of providing shoulders with very different textures to that of the road surface. O'Hanlon and Kelley (1974) evaluated pavement treatments and concluded that paving asphalt-aggregate ribs produced the greatest arousal of a drowsy driver. However, arousal did not last longer than about five minutes.

An alternative pavement treatment which does not require sealing shoulders has been termed the 'hum strip'. It is a series of raised bumps in the centreline and edgelines which produces a hum when drivers run over it (see Vondra, 1977). It is understood that the Road Construction Authority is currently evaluating hum strips on a section of the Maroondah Highway near Coldstream.

The use of rumble strips has not been restricted to counteracting driver fatigue. In Britain rumble strips with variable spacing have been applied to the lanes, rather than the shoulder, in a successful attempt to reduce vehicle speeds approaching intersections (Sumner and Shippey, 1977).

While assessment of on-road countermeasures was not requested as part of this study, more information about the the Californian experience is being sought in the light of the impressive benefit-cost ratios which they have reported.

4.2 FUNCTIONS OF FATIGUE COUNTERMEASURES

Fatigue countermeasures can serve two functions: to maintain driver alertness and/or to monitor driver fatigue. For example, countermeasures such as limitation of hours of work and stipulation of rest periods act to maintain driver alertness, while devices which measure various aspects of driver performance monitor fatigue.

The distinction between maintaining and monitoring driver alertness is an important issue when considering in-vehicle countermeasures. Where an in-vehicle device requires the driver to perform an alerting task in addition to driving, the device acts to help maintain driver alertness. By contrast, other in-vehicle devices which give no immediate feedback to the driver provide a monitoring function. Devices which alert the driver to the need for a rest break and sound an alarm if the driver does not respond accordingly, combine maintaining and monitoring functions.

Some researchers believe that the level of effectiveness required of countermeasures which function by monitoring driver fatigue differs from that required of countermeasures which function by maintaining driver alertness (e.g., Laurell, personal communication, 1988).

It is argued that devices designed to monitor driver fatigue must very highly reliable because drivers may depend upon them, stopping for a rest only when the device warns that fatigue has reached a dangerous level. If a fatigue monitoring device failed to issue a warning signal when the driver was in fact fatigued the driver might continue to drive and eventually fall asleep with the occurrence of an accident quite likely. On the other hand, if the device commonly gave false warning signals the driver might disconnect it, rendering the device ineffective.

Researchers such as Laurell consider that the precision required to guarantee such high reliability of devices does not yet exist and therefore they judge it to be more useful to concentrate on devices which function by maintaining driver alertness. They assume that devices to maintain driver alertness do not need to be highly reliable but it may be that drivers would depend on such devices in the same way as devices to monitor driver fatigue.

There has been little or no research on drivers' responses to warnings produced by driver fatigue monitors. It is often assumed that the driver is motivated to respond to the warning, but the driver is also motivated by deadlines and other pressures to continue driving. Uncertainty also exists as to the length of rest break which should be taken after fatigue develops.

4.3 DRIVER FATIGUE MONITORS

Research in developing in-vehicle fatigue monitors has focussed on the measurement of psychophysiological variables and vehicle control behaviour. A description of the research and the advantages and disadvantages of these methods are discussed in Appendix 7 while the resulting devices will now be described.

4.3.1 Psychophysiological devices

From the background research devices which monitor eye closure and head nodding have been developed.

Eye closure monitoring device. Näätänen and Summala (1978), in a review of problems associated with operationally defining and validating fatigue measures, concluded that falling asleep at the wheel is the only aspect of fatigue that has been shown to directly cause accidents. Measuring eye closure is a reasonably straightforward method of determining whether the driver is about to fall asleep at the wheel, or has already done so.

An optical electronic device which senses eye closure and sounds an alarm after 0.5 seconds has been developed by Xanadu, an Israeli company. The device which is called 'Onguard' consists of a small infra-red sensing unit which observes the eye, and an electronic processor which contains batteries, alarm buzzer, and switch (see Figure 5). The device is designed to be mounted on any standard eyeglass frame.

The relative reflectiveness to light of the eyelid and eyeball are continually compared by the electronic processor. An alarm is activated approximately 0.5 seconds after the eyelid begins to shut should the eyelid not open in time.

Lisper, Laurell and van Loon (1986) found that subjects reported a period of time ranging from a few minutes to half an hour in which they fought off sleep, before finally dozing. The Onguard device could be very useful as an early indicator of the onset of sleep. Because the criterion for eyelid closure has been set at 0.5 seconds, Onguard provides early detection of drowsiness.

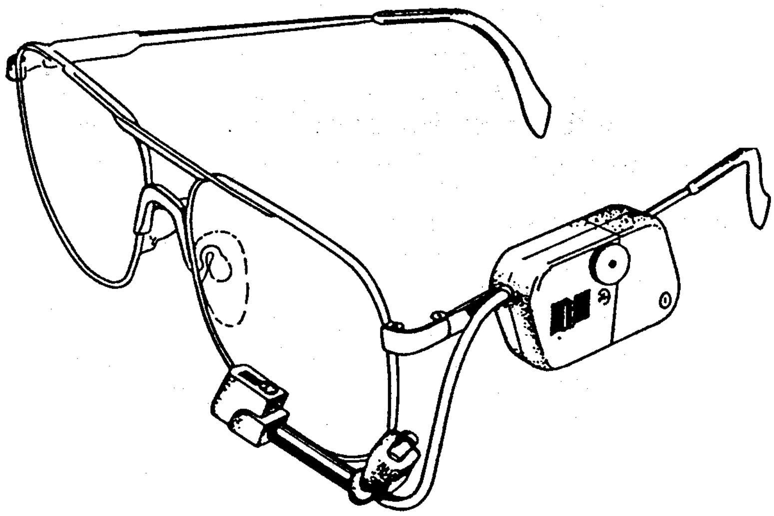


Figure 5. The Onguard eye closure monitor.

One limitation of the device is that it will not operate through lenses that have a mirror-like reflective coating. Another possible disadvantage of the device is that it may be affected by movement of the spectacle frame on the nose. This will be further investigated in the laboratory evaluation of the device. A third problem is that it relies on drivers wearing the device for its effectiveness. However, it is a very simple and cheap mechanism that has much potential.

Like most devices which utilise a psychophysiological measure the degree of intrusiveness of Onguard requires further investigation. However, the device does not require the driver to perform any additional tasks to prevent the alarm sounding and the electronics are relatively sophisticated.

Head nodding monitor. A number of companies have marketed simple devices to monitor head nodding by drivers. The devices consist of an ear piece which hooks over the ear and contains a battery, an alarm and a movement detector. When the driver's head nods forward beyond a predetermined angle, the device buzzes loudly.

Underlying the development of these products is the assumption that head nodding occurs at the onset of fatigue. Hulbert (1972) noted that alertness often decreases substantially before the head begins to nod. There is therefore some possibility that head nodding monitors may sound the alarm signal too late for safety. However, the devices are economical (between $10 and $30), commercially available and do not require the driver to perform any additional tasks. The 'Dozer's Warner', a locally available device, will be further investigated during the evaluation phase of the study.

4.3.2 Devices which monitor vehicle control behaviour

There are a number of vehicle control behaviours which can be easily monitored, e.g., steering patterns and brake and accelerator pedal usage. The research summarised in Appendix Six shows steering patterns to be the vehicle control behaviour which provides the most valid measure of driver fatigue. Devices which monitor steering patterns are described first and then tachographs are discussed.

Stay-A-Wake. This device and the Life Technology-Ford 'Owl' are described in a US review of driver attention monitoring systems by Bishop, Madnick, Walter and Sussman (1985). Stay-A-Wake was developed by the Reli Corporation of Markle, Indiana and monitors speed and steering behaviour. An alarm sounds if no steering movements (reversals or advancements) are made within a three to seven second period. The length of this period can be adjusted by the driver. If the driver has not responded after one second from the commencement of the alarm, the cruise control is disabled and the vehicle's horn sounds. The device can also be used to monitor speed, the alarm sounding if the selected speed is exceeded.

Bishop et al. advise that the device retailed for about $170 US in 1985. The device is not available in Australia and its application is limited to vehicles fitted with cruise control.

Life Technology-Ford 'Owl'. This device compares the driver's current steering reversal rate with that recorded during the first three minutes of driving at a speed greater than 35 mph. An alarm sounds if the reversal rate drops too low, an indicator of drowsiness. A light comes on if the reversal rate becomes too high because this may indicate that the driver is going too fast for the road conditions.

Bishop et al. (1985) report that a representative of Ford's Driver Safety Division informed them that the test drivers eventually tired of the warning system and turned the level control down in order to defeat the system. The device is no longer marketed in the United States.

Safety Drive Advisor. The Safety Drive Advisor was developed in Japan by the Nissan Motor Company (see Figure 6). The device comprises a driving time measure, a dashboard display of recommended rest-break times and a monitor of erratic steering behaviour.

The timing device measures two-hour periods from departure in fine, daylight conditions. At the end of this time a "coffee cup" is displayed on the dashboard and a buzzer sounds. If the driver fails to either turn off the ignition for five minutes or the car does not remain stationary for this time, a buzzer sound is emitted each subsequent hour. For evening (lights on) driving or inclement weather (windscreen wipers on) the rest breaks are timed at shorter intervals.

The Safety Drive Advisor (SDA) measures erratic steering behaviour by memorising the driver's normal steering habits. The input source is the photo-optical steering angle and velocity sensor built into the steering wheel. The device subsequently compares the analysed steering behaviour with the baseline information to detect evidence of erratic steering behaviours indicative of drowsiness and alerts drivers accordingly.

The Safety Drive Advisor appears to be the most sophisticated commercial device currently available to monitor fatigue and alert drivers to drowsiness. As with all fatigue monitoring devices the problem of setting criterion levels of performance, below which an alerting signal is actuated, is also relevant to the development of the SDA. Moreover, a criticism can be made of the method used by Nissan to analyse driver steering patterns, which provided the basis for setting the criterion level of drowsiness.

Nevertheless, the SDA appears to be a promising in-vehicle countermeasure. It does not interfere with the driver's ability to safely drive the vehicle and so has the advantage of not being intrusive.

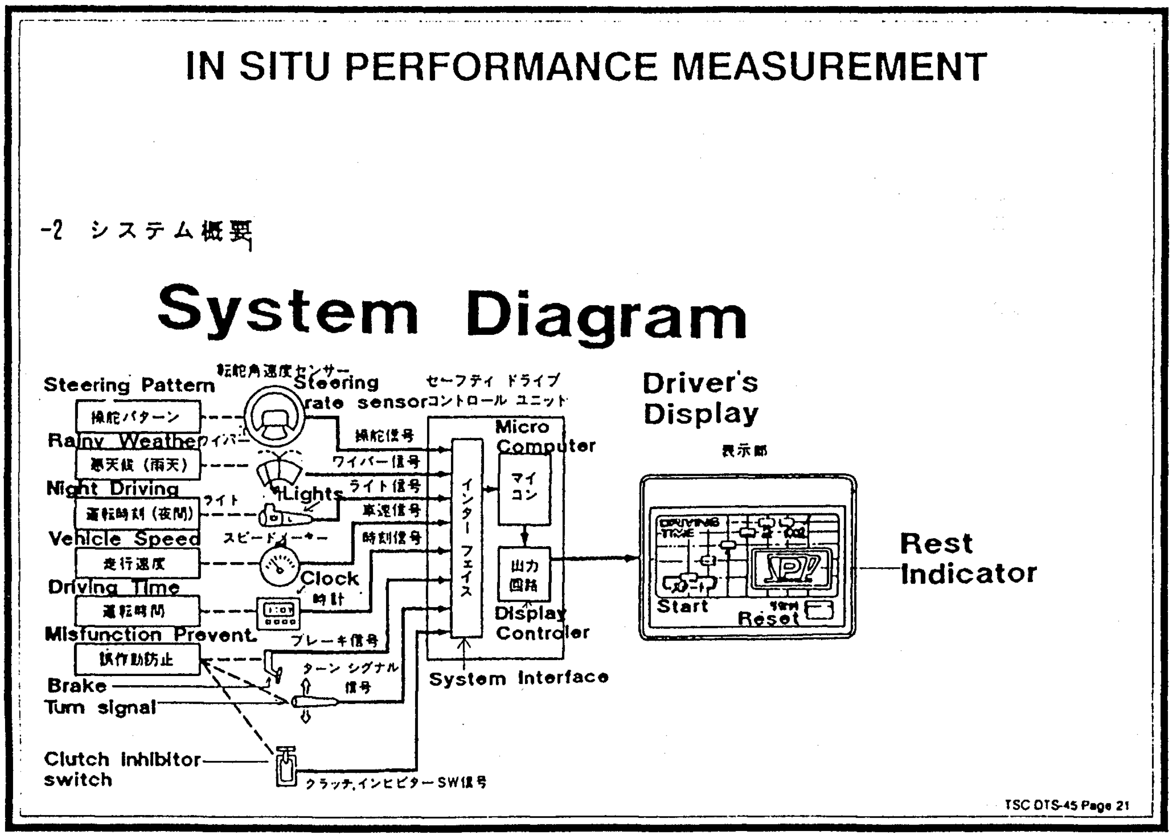


Figure 6. A schematic representation of the Nissan Safety Drive Advisor.

The SDA was designed as a component of the electronic power steering system built into some models of the Nissan Bluebird Maxima available in Japan and the United States. However, Nissan have advised that due to a low market demand for this product, they have decided not to offer it as a standard feature in future releases of their vehicles and have advised that the unit is not available in Australia.

This discussion of vehicle control behaviour monitors of driver fatigue suggests that measures of steering patterns may be useful in detecting fatigue but relatively complex analyses are necessary, absence of steering movements or a change in reversal rates alone does not seem to provide an adequate measure.

Tachographs. State-of-the-art tachographs are actually on-board computers that provide a comprehensive vehicle management system. In addition to road speed and engine rpm they provide information on idling and engine shut-off and allow for extensive driver input. Information processing after the trip is computerised and a wide variety of reports is available including analysis of data over an extended time-period.

There are no studies available which directly assess the effectiveness of tachographs in reducing the number of fatigue-related accidents but studies exist which examine the relationship between driving hours and accidents.

Jones and Stein (1987) conducted a study of large truck crashes in the United States. They compared the characteristics of trucks and drivers which crashed at particular sites to trucks and drivers which passed the same site at the same time, a week later. They found that the relative risk of crash involvement for drivers whose reported driving time exceeded eight hours was almost twice that of drivers who had driven fewer hours. Because tachographs have the potential to regulate driving hours they could thereby reduce accidents due to excessive driving time.

The Insurance Institute for Highway Safety (IIHS) advises that most of the US carriers of hazardous materials have been using tachographs for two decades. "They have found that the devices increase efficiency, reduce speeding, and are valuable for accident reconstruction" (Williams, personal communication, 1988). The role of tachographs in monitoring hours of driving has obvious benefit as a fatigue countermeasure. The increased safety that derives from monitoring speed and driving time highlights the potential benefits of using tachographs.

In many countries within the European Economic Community tachographs are mandatory in commercial trucks with a gross vehicle mass of more than 7,000 kilograms and buses whose routes exceed 50 kilometres (letter from Insurance Institute for Highway Safety to Office of Motor Carrier Safety, 1986). In the United States tachographs are not mandatory but there are moves to make them so. In 1987 the Federal Highway Administration issued an Advance Notice of Proposed Rule-Making requesting comments about the use of on-board recording devices in motor vehicle operation in interstate commerce.

In the National Roads and Motorists' Association (NRMA) Submission to the New South Wales Standing Committee on Road Safety in 1986 tachographs were recommended as devices which could replace log books and provide continuous monitoring of how the truck was being driven. It was noted that log books are largely ineffective as a method by which hours of driving can be accurately monitored.

Tachographs can provide accurate monitoring of driving hours but it is unclear whether their mandatory introduction is the best way to reduce the extent of fatigue in crashes. The current legislation in Victoria limits the hours of work by drivers. Hours of work include driving time, loading and unloading time and waiting time. McDonald (1985) noted that time spent at work is time which cannot be used for rest. Even if this time includes idle periods such as waiting, it still constitutes work and should therefore be included in the work period. As all of these activities contribute to the onset of driver fatigue it is sensible to have regulations which cover them all. Thus a limitation of tachographs is that they cannot monitor the total time spent at work, only that portion during which the truck engine is running.

For tachographs to be effective countermeasures their use would have to be enforced. This enforcement would need to occur at both the levels of trucking companies and the government.

Tachographs are insensitive to the physical condition of the driver (including amount of rest before commencing the shift) and to environmental conditions (e.g., excessive heat). Past research has shown that these factors may shorten the length of the driving period before fatigue is evident.

The need for effective fatigue countermeasures has been highlighted by the decision of the Australian Transport Advisory Council (ATAC) to recommend changed driving hours legislation. The recommended legislation represents an increase from the previous Victorian legislation (maximum of 12 hours per day, 72 hours per week) up to a maximum of 15 hours per day, 75 hours weekly and 150 hours fortnightly. ATAC recommended enhanced log book information and the optional use of tachographs. While tachographs can provide effective monitoring of driving hours, their usefulness in reducing fatigue-related accidents is limited if the legal limit is high.

There is some potential for sophisticated tachographs to be developed to monitor driver alertness. This would require measurement of a number of vehicle-related factors which could be analysed and the driver alerted if they reached a dangerous level. Such a modification could produce a tachograph with additional advantages similar to the Nissan Safety Drive Advisor.

4.4 MAINTAINING DRIVER ALERTNESS

Fatigue countermeasures which function by maintaining driver alertness include subsidiary reaction time devices and driver strategies. Subsidiary reaction time devices both maintain driver alertness and monitor driver fatigue but the driver strategies have no monitoring, only an alerting function.

4.4.1 Reaction time devices

A fatigue alerting device based on a visual signal and reaction time clock has been developed by a Danish company. This device is called Roadguard and consists of an electronic circuit which is activated by the gear-box when the vehicle is put into top gear. A timer comes on which stops at random periods after 4 to 14 seconds. When the timer stops, a red lamp lights up on the instrument panel. The lamp can be switched off using either of two light touch contacts on the steering wheel or a foot switch. If it is not switched off within three seconds an alarm buzzer begins to sound. If the lamp is switched off the timer begins a new sequence.

The device was the invention of a Danish haulage contractor and it can be fitted to most trucks in approximately two hours. While the manufacturers insist that switching off the lamp in no way interferes with the driver, the issue of intrusiveness requires further investigation. In conducting the laboratory evaluation of this device the level of intrusiveness will be assessed.

An additional issue is the length of time which elapses between the light coming on and the device sounding an alarm. For the device to be useful, fatigue must be detected quickly in order to enable the driver to avoid a possible accident. Lisper, Laurell and van Loon (1986) found that drivers who fell asleep at the wheel, in an experiment involving driving around a closed circuit track, did so for brief periods only, ranging from 0.5 to 1.5 seconds. By setting the criterion RT at three seconds it is possible that detection of drowsiness may not be sufficiently rapid to prevent accidents. This will be further investigated in the laboratory evaluation of the device.

4.4.2 Driver strategies

The driver strategies described in this section are auditory input (car or Citizens' Band radio), control of cabin temperature and alerting 'games'.

Auditory input. In a survey conducted by the Traffic Authority of NSW (Webster, 1987), a commonly reported strategy to help overcome fatigue was listening to the AM/FM radio or CB radio. This was used to either 'sing along to' or talk to other drivers in an effort to stay awake. These results are in agreement with an earlier German study (Prokop and Prokop, 1955, cited in Langlois, Smolensky, Hsi, and Weir, 1985).

There is some evidence from general and driving-related studies that auditory input is likely to be effective in maintaining alertness (Fagerstrom and Lisper, 1977; Hartley and Shirley, 1977; Hockey, 1970; Wilkinson, 1963).

The effect of loud noise on a driving-like task was studied by Hockey (1970). Loud noise improved detection of stimuli presented directly in front of the subject but led to deterioration in detection of stimuli presented to the side of the subject. The deterioration over time (fatigue effect) was less during loud noise.

The use of noise as a fatigue countermeasure gains support from studies of the effect of noise under conditions of sleep deprivation.

Addition of noise to a task has been shown to reduce the deficit in performance caused by sleep loss (Hartley and Shirley, 1977; Hattori, Matsuura, Narumiya, Araki and Ohnaka, 1987; Wilkinson, 1963). Noise seems to have a more positive effect on early morning performance (Blake, 1971 cited in Jones, 1983; Mullin and Corcoran, 1977). Hartley and Shirley found that partial sleep loss led subjects to perform more riskily (they were more likely to identify a stimulus that was not there) whereas noise led to more cautious responding.

The difference in the effects of sleep deprivation and noise seem to be in the pattern of performance, rather than an overall difference in efficiency (Hockey, 1973). Using a multisource monitoring task Hockey demonstrated that loud noise increased sampling of the source associated with high fault probability while sleep loss resulted in a reduction of sampling of the high probability source.

There are few driving-related studies of the effect of auditory input upon performance. Fagerstrom and Lisper (1977) showed that listening to the car radio reduced the slowing of reaction times that occurred after several hours driving. But the benefit was greater for subjects classified as extroverts than those classified as introverts. This finding serves as a reminder that characteristics of individual drivers may influence the effectiveness of countermeasures.

Hattori et al. (1987) conducted an experiment in which vibration synchronised with music was used to help keep drivers alert. The results were as follows: "music stimulation was found to be effective to heighten the alertness level of driver subjects, but the duration of the effect was short because of habituation. The addition of the vibrational stimulation synchronised with the music was judged to be more effective" (p.249.2). The findings indicate that auditory stimulation can be useful in maintaining alertness but not for extended periods (where it would be more useful to rest).

Listening to information which requires a higher level of concentration than that which is required for listening to background music is more alerting. Snook and Dolliver (1976) found recordings of "Newsweek", a current affairs magazine, to be more effective in helping drivers maintain alertness than recordings of background music of the type played on answering machine waiting queues.

Circulation of cool air. Many drivers state that they take steps to increase the circulation of cold air when feeling drowsy. Keeping the interior of the vehicle well ventilated and cool was recommended as a fatigue countermeasure by McKnight and Hume (1979) in their report to the US Department of Transportation on Identifying Accident Avoidance Behaviours.

Scientific evidence exists that human performance deteriorates in hot (and cold) conditions (e.g., Bursill, 1958; Grether, 1973) but little research has been conducted into the efficacy of cold air in reducing drowsiness.

Mackie and O'Hanlon (1977) studied the effect of heat stress on extended driving. Drivers in the hot environment rated themselves as more alert early in the trip than drivers in the comfortable condition but rated themselves as more fatigued and less alert in the second half of the trip than drivers in the comfortable condition. Measurements of vehicle control behaviour reflected the subjective reports.

While there is evidence that the onset of fatigue is faster in hot than comfortable conditions, there is no experimental evidence that taking steps to increase the circulation of cold air will reduce a pre-existing state of drowsiness.

Alerting 'games'. In a study of truck drivers' susceptibility to monotony, McBain (1970) observed that drivers engaged in behaviour designed to reduce the monotony of highway driving. He reports that

> drivers spotlighted deer by the side of the road with practiced accuracy, signalled to other drivers, observed and commented on the idiosyncrasies of other drivers, pointed out changes in road and other construction projects visible since they had last been seen, and in these and many other ways kept themselves almost constantly occupied. (p. 518)

Observations made during highway driving and drivers' comments suggested that exposure to monotonous work conditions need not inevitably lead to lapses of attention followed by accidents. Drivers may learn behaviours to reduce the loss of efficiency associated with exposure to such conditions. This was supported by the laboratory finding that experienced drivers (who reported little reaction to monotony on the job) showed the most variability in reaction time.

It may helpful to educate and encourage drivers to engage in behaviour to reduce monotony on long trips.

4.5 CONCLUSIONS

In-vehicle countermeasures have been developed which have the ability to monitor driver fatigue and/or maintain driver alertness. Other classes of countermeasure may also be viable. Pavement treatments such as rumble strips have been shown to be effective in alerting dozing drivers in experimental studies and one evaluation after installation has reported high benefit-cost ratios.

In evaluating in-vehicle countermeasures, the distinction between devices which function by maintaining driver alertness and those which monitor driver fatigue is important. Some researchers feel that drivers will depend on devices which monitor driver fatigue and for this reason such devices require a higher standard of reliability.

Of the countermeasures which function by monitoring psychophysiological responses, the eye closure monitor and the head nodding monitor have potential. These will be tested in the next stage of this project.

Research has shown some indices of vehicle control behaviour to be valid measures of fatigue. The most promising measure is analysis of steering patterns, although these analyses need to be reasonably complex. The Nissan Safety Drive Advisor which measures steering patterns and driving time appears to be the most sophisticated device produced commercially. Although it is not available in Australia and is unsuitable for laboratory testing, more information about the device is being obtained in the hope that it may be tested in a further project. Tachographs can be used for monitoring driving hours but their potential for feedback of dangerous control actions to the driver has not been realised. They are not suitable for laboratory testing in the next stage of this project and would be better evaluated by a field study.

Devices which require a reaction time task to be performed while driving have been developed to maintain driver alertness. It is intended to test the Roadguard device (or a similar device) in the next stage of this project.

There are a number of driver strategies to maintain alertness. General and driving-related studies have shown that addition of noise acts to reduce fatigue, particularly in extroverted subjects. There is need for further research before firm conclusions can be drawn about the effects of circulation of cool air and of alerting 'games'.

4.6 CRITERIA TO BE USED IN TESTING IN-VEHICLE FATIGUE COUNTERMEASURES

The foregoing review of in-vehicle fatigue countermeasures has identified three criteria which should be used in laboratory testing in the second stage of this project. These are reliability, criterion level and level of intrusiveness.

Reliability of in-vehicle fatigue countermeasures has been identified as an important issue by other researchers (e.g., Laurell, personal communication, 1988). If drivers learn to depend upon the device it needs to always detect the presence of fatigue and rarely give false alarms.

The criterion level of a device is the level of driver fatigue that is reached before the device warns the driver of danger. A warning given too early is equivalent to a false alarm but failure to warn the driver before he or she falls asleep at the wheel may render the device ineffective.

The level of intrusiveness of a device needs to be established. By this it is meant the degree to which the driver is annoyed by the device and the amount of interference with the driving task.

Each of the devices which have been selected for laboratory testing appears to be questioned by one or more of the criteria. Onguard, the eye closure monitor, may not be reliable if it slips on the nose and might be considered intrusive by drivers. Concern has been expressed (Hulbert, 1972) that the head nodding monitor may have an excessively high criterion level. This concern also applies to Roadguard, the driver reaction time device. In addition, it is not clear whether Roadguard is considered intrusive by drivers.

Failure to conform to the criteria does not necessarily imply that the concept embodied in the device is a poor one. It may be that adjustment of parameters or redesign would result in an effective device.

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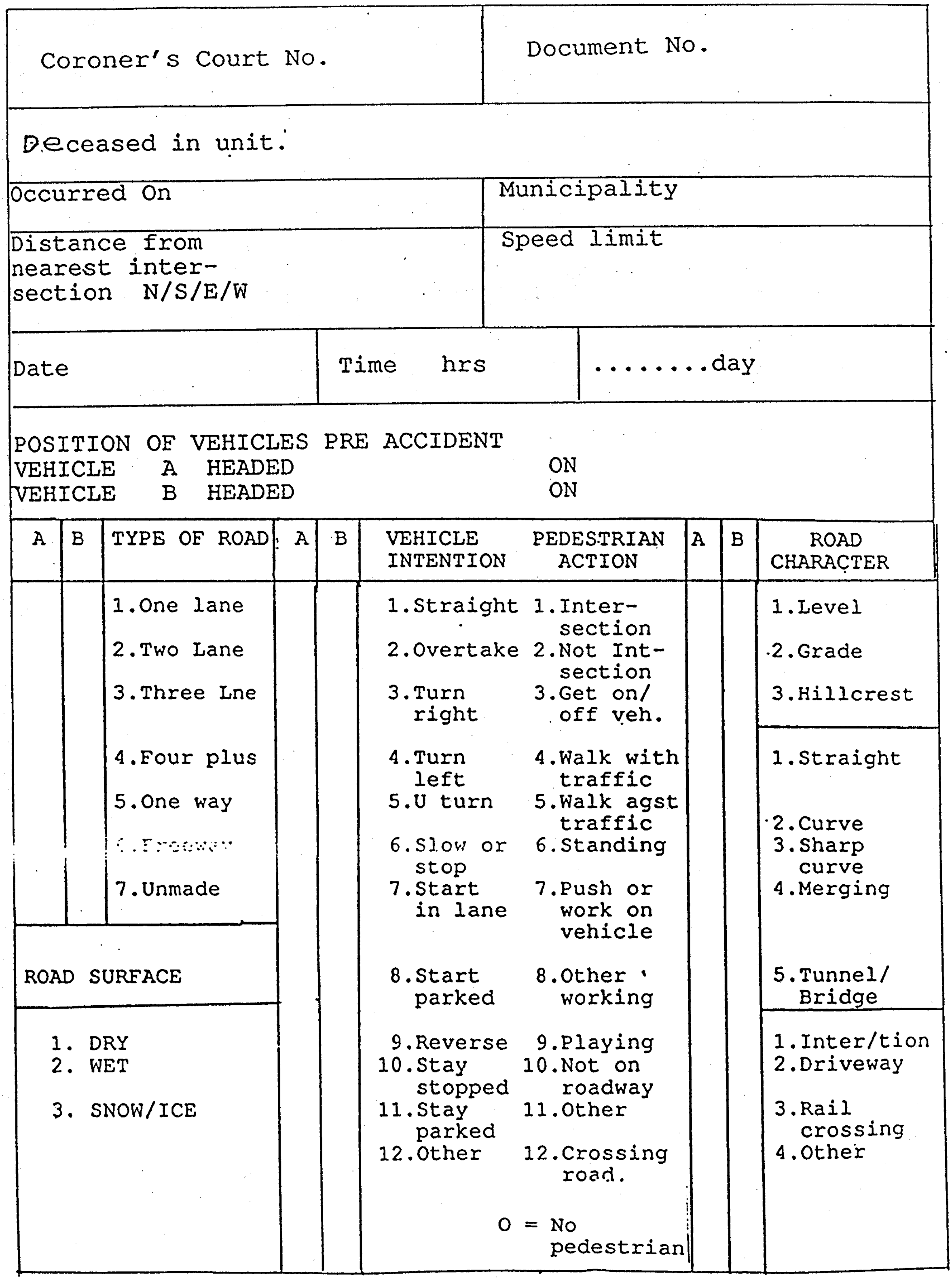
APPENDIX ONE
FORM FOR RECORDING DATA FROM CORONERS RECORDS AND LIST OF VARIABLES RECORDED



Coroner's Court No.	Document No.
Deceased in unit.	
Occurred On	Municipality
Distance from nearest inter-section N/S/E/W	Speed limit

Date	Time hrs	........day

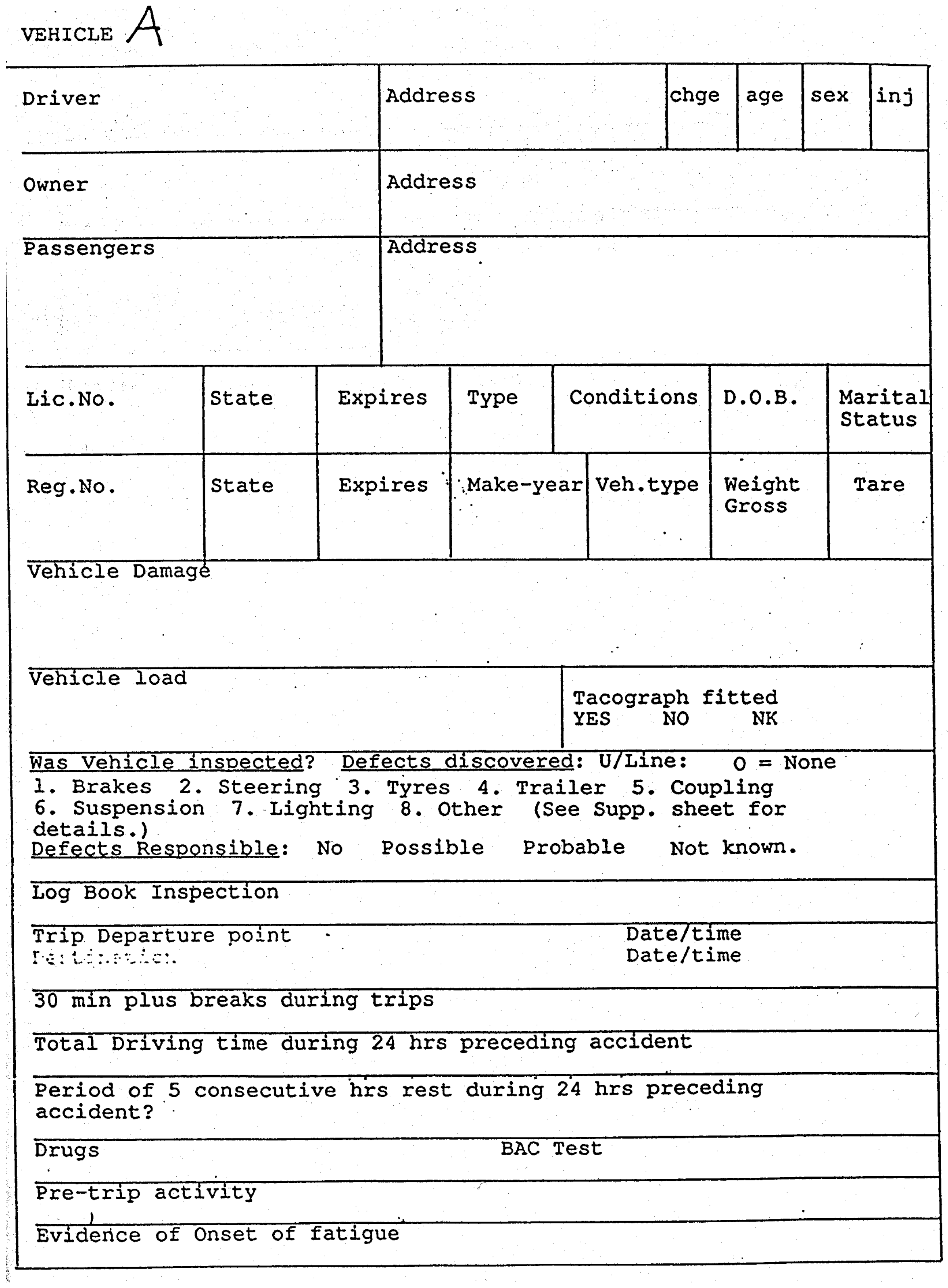
POSITION OF VEHICLES PRE ACCIDENT
VEHICLE A HEADED ON
VEHICLE B HEADED ON

A	B	TYPE OF ROAD	A	B	VEHICLE INTENTION	PEDESTRIAN ACTION	A	B	ROAD CHARACTER
		1.One lane			1.Straight	1.Inter-section			1.Level
		2.Two Lane			2.Overtake	2.Not Int-section			2.Grade
		3.Three Lne			3.Turn right	3.Get on/off veh.			3.Hillcrest
		4.Four plus			4.Turn left	4.Walk with traffic			1.Straight
		5.One way			5.U turn	5.Walk agst traffic			2.Curve
		6.Freeway			6.Slow or stop	6.Standing			3.Sharp curve
		7.Unmade			7.Start in lane	7.Push or work on vehicle			4.Merging
		ROAD SURFACE			8.Start parked	8.Other working			5.Tunnel/Bridge
		1. DRY			9.Reverse	9.Playing			1.Inter/tion
		2. WET			10.Stay stopped	10.Not on roadway			2.Driveway
		3. SNOW/ICE			11.Stay parked	11.Other			3.Rail crossing
					12.Other	12.Crossing road.			4.Other
						0 = No pedestrian			

VISIBILITY		LIGHT	A	B	TRAFFIC CONTROL	A	B	CONTRIBUTING CIRCUMSTANCES
	1. Clear	1.Daylight			1. Stop sign			1. Speed to fast
	2. Rain	2.Dawn/disk			2. Signal			2. Fail to yield R.O.W.
	3. Fog	3.Darkness			3. Field sign			3. Drive right of centre
	4. Dust				4. Barriers			4.Improper overtake
	5. Other				5. Points men			5.Pass stop sign
	SEAT BELTS - DRIVERS				6. Rail gates			6.Disobey T.C.S
	VEH A				7. Other			7.Follow too close
	VEH B							
					8. No control			8.Incorrect turn
								9.Other T.R. breaches
								10.Faulty brakes
								11.Faulty lights
								12.Drugs
								13.Alcohol

SKETCH

ACCIDENT DESCRIPTION



VEHICLE A

Driver	Address	chge	age	sex	inj
Owner	Address				
Passengers	Address				

Lic.No.	State	Expires	Type	Conditions	D.O.B.	Marital Status
Reg.No.	State	Expires	Make-year	Veh.type	Weight Gross	Tare

Vehicle Damage

Vehicle load	Tacograph fitted YES NO NK

Was Vehicle inspected? Defects discovered: U/Line: 0 = None
1. Brakes 2. Steering 3. Tyres 4. Trailer 5. Coupling
6. Suspension 7. Lighting 8. Other (See Supp. sheet for details.)
Defects Responsible: No Possible Probable Not known.

Log Book Inspection

Trip Departure point Date/time
Destination Date/time

30 min plus breaks during trips

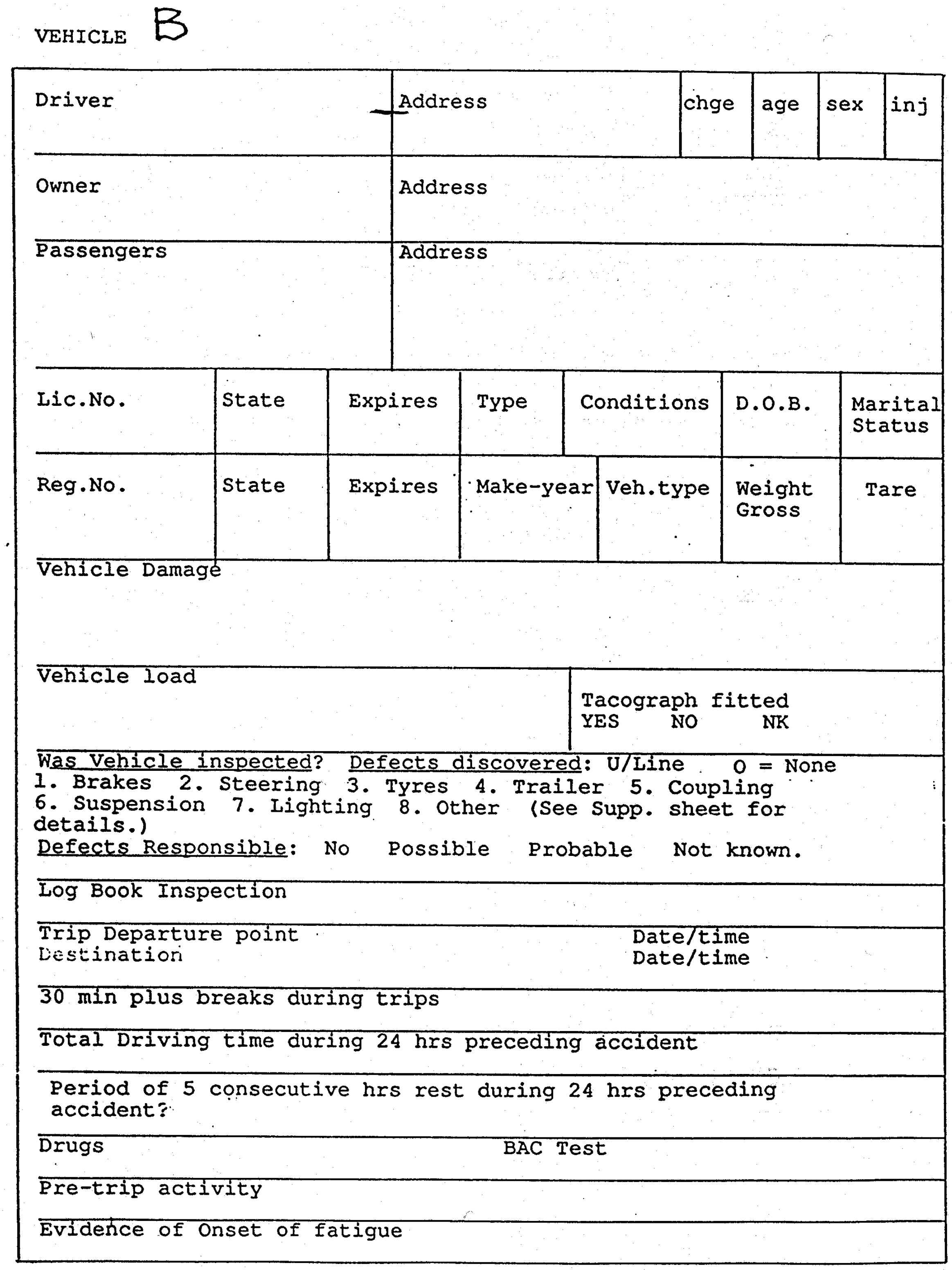
Total Driving time during 24 hrs preceding accident

Period of 5 consecutive hrs rest during 24 hrs preceding accident?

Drugs BAC Test

Pre-trip activity

Evidence of Onset of fatigue



VEHICLE B

Driver	Address	chge	age	sex	inj

Owner	Address
Passengers	Address

Lic.No.	State	Expires	Type	Conditions	D.O.B.	Marital Status
Reg.No.	State	Expires	Make-year	Veh.type	Weight Gross	Tare

Vehicle Damage

Vehicle load	Tacograph fitted YES NO NK

Was Vehicle inspected? Defects discovered: U/Line 0 = None
1. Brakes 2. Steering 3. Tyres 4. Trailer 5. Coupling
6. Suspension 7. Lighting 8. Other (See Supp. sheet for details.)
Defects Responsible: No Possible Probable Not known.

Log Book Inspection

Trip Departure point Date/time
Destination Date/time

30 min plus breaks during trips

Total Driving time during 24 hrs preceding accident

Period of 5 consecutive hrs rest during 24 hrs preceding accident?

Drugs BAC Test

Pre-trip activity

Evidence of Onset of fatigue

PATHOLOGISTS REPORT RE CAUSE OF DEATH

CORONERS FINDING

CULPABILITY

VEHICLE A	VEHICLE B

SUPPLEMENTARY INFORMATION

VARIABLES CODED IN ANALYSIS OF FATAL ACCIDENTS INVOLVING TRUCKS

VARIABLE NO.	ABBREVIATION	VARIABLE NAME
1	Accno	Accident number
2	Acctype	Accident type (1=single-vehicle, 2=truck-car, 3=truck-pedestrian, 4=truck-bicycle, 5=truck-motorcycle, 6=truck-truck, 7=truck-multiple others)
3	Corno	Coroner's Court number
4	Docno	Document number assigned by Registrar General's Office
5	Unit	Number of unit in which deceased was travelling
6	LGA	Local government area number
7	Limit	Speed limit at accident site
8	Date	Date on which accident occurred
9	Time	Time at which accident occurred in 24-hour clock
10	Day	Day of the week (1=Sunday)
11	Surface	Road surface (1=dry, 2=wet, 3=snow/ice)
12	Visibil	Visibility (1=clear, 2=rain, 3=fog, 4=dust)
13	Light	Light conditions (1=daylight, 2=dawn/dusk, 3=darkness)
14	Pedact	Pedestrian action (see form)
Variables recorded for each vehicle		
15	Roadtype	Type of road (see form)
16	Intent	Vehicle intention
17	Roadchar	Road character (1=level, 2=grade, 3=hillcrest)
18	Direct	Road direction
19	Feature	Road features
20	Belts	Drivers wearing seat belts (0=not known, 1=yes, 2=no)
21	Control	Traffic control devices
22	Contrib	Contributing circumstances
23	Owner	Is driver owner? (0=not known, 1=yes, 2=no, 3=not relevant)
24	Age	Age of driver/pedestrian/cyclist
25	Sex	Sex of driver/pedestrian/cyclist
26	Injury	Extent of injury (0=not known, 1=fatal, 2=injury, 3=property damage only, 4=no injury or damage)
27	Pass	Number of passengers
28	LicNo	Licence number
29	LicStat	Licence state
30	LicType	Type of licence
31	RegNo	Registration number

32	RegStat	State of registration
33	Makeyear	Make and year of vehicle
34	Vehcode	Coded vehicle type (1=car, 2=bike, 3=motorbike, 4=pedestrian, 5=light truck, 6=articulated vehicle, 7=rigid truck)
35	VehType	Description of vehicle type
36	Gross	Gross weight of vehicle (kg)
37	Tare	Tare weight of vehicle (kg)
38	Damage	Vehicle damage classification
39	Load	Vehicle load (kg)
40	Tacho	Tachograph fitted? (0=not known, 1=yes, 2=no)
41	Inspect	Vehicle inspected? (0=not known, 1=yes, 2=no)
42	Defects	Defects discovered
43	DefResp	Defects responsible? (0=not known, 1=possible, 2=probable, 3=no)
44	Log	Log book inspection (0=not inspected, 1=inspected, OK, 6 2=inspected, violation)
45	Depart	Trip departure point
46	DepTime	Trip departure time
47	Destin	Destination
48	ETA	Estimated time of arrival
49	30min	Number of 30+ min breaks
50	24total	Total driving time in previous 24 hours (e.g., 200=2 hours)
51	Rest	Period of 5 hours consecutive rest during previous 24 hours? (Y=yes, N=no)
52	Drugs	Drugs present? (0=not known, 1=not found, 2=found)
53	BAC	(0=not measured, 1=OK, 2=illegal)
54	Pretrip	Pre-trip activity

Variables 15 to 54 are repeated for the second vehicle. These are coded as variables 55 to 94.

95	Find	Coroner's finding
96	Culp	Culpability
97	Suppl	Supplementary inf available (1=yes, 2=no)

APPENDIX TWO
FATIGUE-RELATED VARIABLES IN CORONERS' RECORDS

Some fatigue-related variables were present both in the Coroners' records and in the data base of Police-reported accidents maintained by the Road Traffic Authority (RTA). Comparisons of the distributions of these variables in these two data sources are presented here. The purpose of the comparisons was to investigate whether the available Coroners' records constituted a representative sample of accidents involving trucks.

Number of vehicles involved in the accident

The accident sample derived from Coroners' records was divided into accidents which involved a truck only and accidents which involved a truck and either a car, a pedestrian, a bicyclist, a motorcyclist, another truck or multiple other vehicles. The relative frequencies of the different types of accidents are shown in Table A2.1.

Table A2.1. Types of fatal accidents involving trucks (from Coroners' records).

Accident type	Frequency	Percentage
Truck-only	20	10.8
Truck-car	99	53.5
Truck-pedestrian	21	11.4
Truck-bicycle	8	4.3
Truck-motorcycle	18	9.7
Truck-truck	7	3.8
Truck-multiple others	12	6.5

Analysis of the Coroners' records showed that truck-only accidents comprised 10.8% of the sample of fatal accidents involving trucks. In the RTA data 12.0% of fatal and casualty truck accidents were truck-only. Truck-pedestrian accidents made up 5% of the RTA sample and a larger proportion of fatal accidents (24.3%) than casualty accidents (16.8%) were single-vehicle (truck-only or truck-pedestrian, z=3.70, p<.05).

Of the 21 pedestrians killed in the Coroners' records, three were males with elevated BACs, three were young children and ten were persons over 60 years of age.

Day of the week

The proportions of all and single-vehicle accidents which occurred on each day of the week in the Coroners' records and the RTA data base are presented in Table A2.2.

Statistical analysis of the Coroners' data failed to show differences across the week (c2=26.6, p<.05) in the frequency of all accidents. In contrast, analysis of the RTA data base showed that the frequency of truck accidents was not the same for all days of the week (c2=607.92). Inspection of Table A2.2 suggests that accident frequencies were highest on Fridays and lowest on the weekend.

Table A2.2. Distribution of all and single-vehicle accidents across the week.

Day	All accidents (%)		Single-vehicle accidents (%)	
	Coroners'	RTA	Coroners'	RTA
Sunday	8.1	4.4	5.0	6.8
Monday	14.0	16.0	15.0	14.4
Tuesday	12.9	17.0	45.0	15.2
Wednesday	19.9	17.9	5.0	18.2
Thursday	15.1	17.2	5.0	15.7
Friday	17.7	19.3	15.0	19.3
Saturday	12.4	8.2	10.0	10.5

Because of the small number of single-vehicle accidents (20) in the Coroners' records, statistical analysis of these data was not attempted. In the RTA data, the proportion of accidents which were single-vehicle was highest on Sunday (26.9%) and Saturday (22.1%).

Time of day

Analyses of the Coroners' records showed that accident frequency varied as a function of time of day (c2=31.2, p<.05). In Figure A2.1 mid-morning and late-afternoon peaks can be discerned. The time of day pattern was similar in the RTA data (c2=127.0, p<.05). Table A2.3 shows that accident frequency was greatest in the two-hour period from 1000 hours to 1200 hours (15.3%) and was generally elevated (>12%) from 800 to 1800 hours.

Data from both sources showed that night-time accidents comprised a greater proportion of accidents involving articulated vehicles than accidents involving rigid trucks. In the Coroners' data, the proportion of articulated vehicles involved in accidents in the period from 6 p.m. to 6 a.m. was higher (38.8%) than the proportion of rigid trucks involved in accidents in those hours (25.8%, z=1.74, p<.05). The night-time proportions were 31.2% and 14.8%, for articulated and rigid trucks in the RTA data (z=9.4, p<.05).

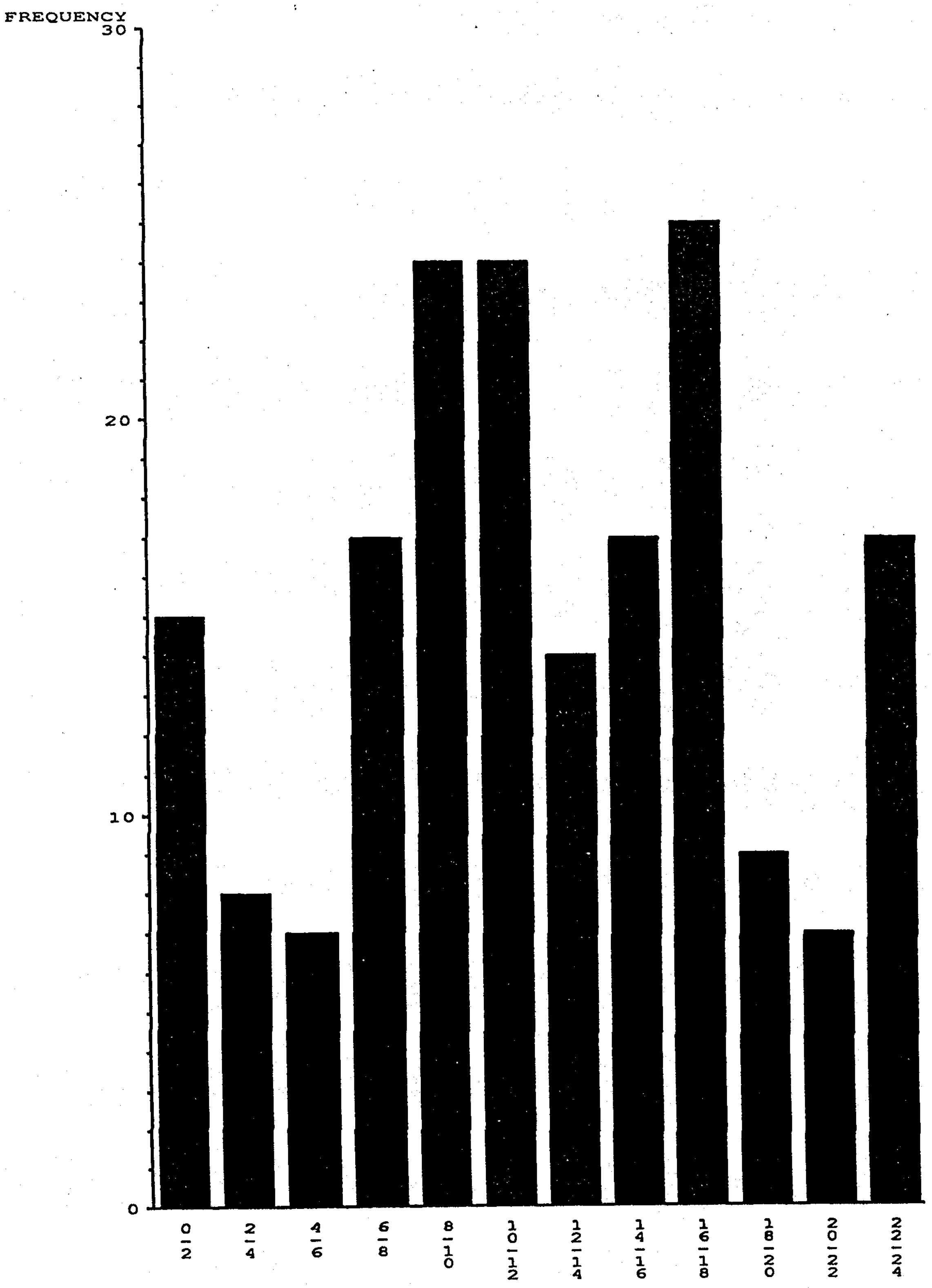


Figure A2.1. Time of occurrence (in two-hour blocks) of fatal accidents involving trucks (from Coroners' records).

Table A2.3. Time of occurrence of fatal and casualty accidents involving trucks (from RTA data).

Time	Frequency	Percentage
0-200	22	2.7
200-400	97	2.1
400-600	129	2.8
600-800	437	9.6
800-1000	642	14.1
1000-1200	698	15.3
1200-1400	631	13.9
1400-1600	645	14.7
1600-1800	568	12.5
1800-2000	282	6.2
2000-2200	160	3.5
2200-2400	141	3.1

Blood alcohol concentration

An analysis of the Coroners' records of blood alcohol concentration (BAC) by type of vehicle driven is presented in Table A2.4. It shows that 14 of 90 car drivers (15.6%) had readings exceeding .05% BAC. In contrast, only 4 of 76 (5.3%) articulated vehicle drivers tested and 3 of 35 (8.6%) rigid truck drivers tested had an illegal BAC. Other persons found to have BAC's exceeding .05% were 4 of 12 motorcyclists (33.3%), one of five pedestrians (20%) and one of only two light commercial vehicle drivers in the sample. Statistical analysis shows that the proportion of truck drivers who were alcohol-impaired is lower than the proportion impaired of other participants (z=2.81, p<.05). Care must be taken in using the other percentages in Table A2.4 because of the small numbers involved.

Table A2.4. Blood alcohol concentrations of participants in fatal accidents involving trucks

Participants	Number with BAC>.05	Number tested	Percentage with BAC>.05
Car drivers	14	90	15.6
Bicyclists	1	3	33.3
Motorcyclists	4	12	33.2
Pedestrians	1	5	20.0
Light truck drivers	1	2	50.0
Articulated vehicle drivers	4	76	5.3
Rigid truck drivers	3	35	8.6

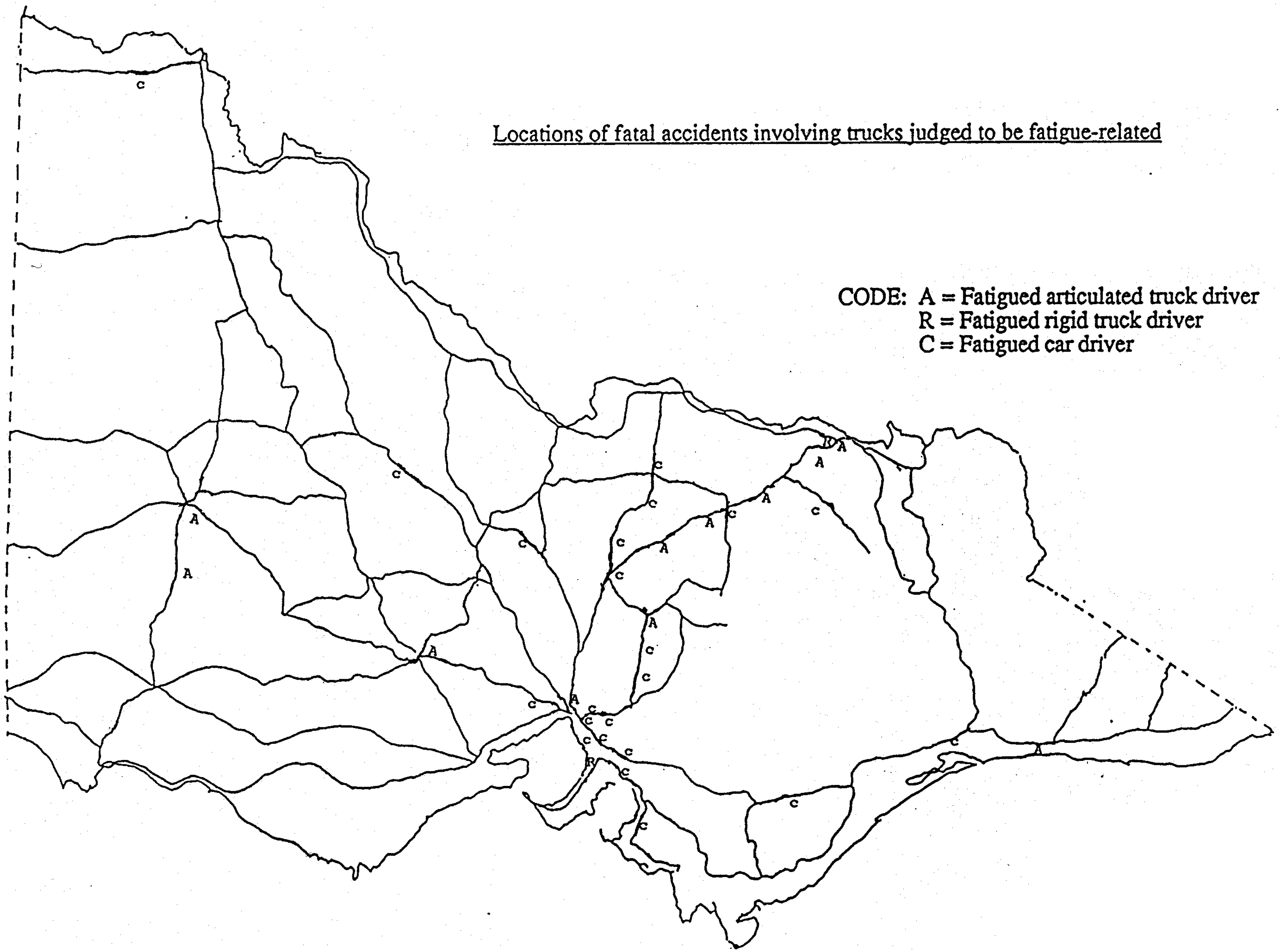
The difference in proportion of truck and car drivers alcohol-impaired was not found in the RTA data. Analyses of those data showed that 11.2% of car drivers tested had BACs exceeding .05% as compared with 13.5% of articulated vehicle drivers and 8.1% of rigid vehicle drivers.

It should be noted that the proportion of drivers tested for alcohol impairment differed with vehicle type in the Coroners' data. A higher percentage of car drivers (83%) than articulated vehicle drivers (64%) and drivers of rigid trucks (56%) were tested ($z=3.30$, $p<.05$). This may be a result of the legislation requiring BAC testing of persons killed or treated at a hospital only. Fewer truck drivers than car drivers died or required hospital treatment. Thus, the reliability of the proportions of alcohol-impaired truck drivers is lower than that of car drivers.

APPENDIX THREE
LOCATIONS OF FATIGUE-RELATED ACCIDENTS

Road	Fatigued Driver		
	Car	**Articulated vehicle**	**Rigid truck**
Highways			
Bass	1	0	0
Calder	1	0	0
Goulburn Valley	3	0	0
Henty	0	1	0
Hume	2	7	1
McIvor	1	0	0
Melba	2	1	0
Princes East	2	1	0
South Gippsland	1	0	0
Sturt	1	0	0
Western	1	2	0
Non-highway locations			
Metropolitan Melbourne	6	0	1
Traralgon	1	0	0
Rural roads	1	0	0

Locations of fatal accidents involving trucks judged to be fatigue-related



CODE: A = Fatigued articulated truck driver
R = Fatigued rigid truck driver
C = Fatigued car driver

APPENDIX FOUR
LOCATIONS OF VEHICLE COUNTING STATIONS

Highway	Station Number	Location
Princes Highway West	150	East of Portland
Western Highway	605	At Dadswells Bridge
Calder Highway	104	At Derby
Hume Highway	229	Near Balmattum
Murray Valley Highway	348	East of Cobram
Princes Highway East	496	At Fernbank

APPENDIX FIVE
ADJUSTING FOR EXPOSURE

Exposure is defined as the opportunity to have an accident and several measures of exposure exist. The most common is to assume that opportunity to have an accident is linearly related to distance travelled or, less commonly, time spent travelling.

Exposure corrections are commonly computed to compare the relative risks of populations which vary in their level of exposure. The survey of motor vehicle use conducted by the Australian Bureau of Statistics for the year ending 30th September, 1985 showed that exposure to risk differs between articulated vehicles, rigid trucks and cars. On average, semi-trailers travel 4.6 times further per year than cars and that rigid trucks travel 1.2 times further per year than cars. It is often necessary to divide accidents per registered vehicle (or thousands thereof) to arrive at a figure which gives relative risks per distance travelled.

The exposure adjustment conducted in this study differed somewhat from the "standard" adjustment. The measure of exposure used was the number of vehicles on the road (often termed the vehicle count or traffic volume) in each two-hour time period.

There are a number of limitations to the simple exposure adjustment used in this report. Ogden and Tan (1987) suggest the use of a different numerator and Cowley (1978) questions the use of a single denominator.

In the current study the numerator was the number of truck accidents. Ogden and Tan (1987), in their discussion of the options available in computing truck accident rates, suggest that a more appropriate numerator is the number of trucks involved in accidents. This is a slightly larger number because of the existence of accidents involving more than one truck. Thus, the effect of using the number of truck accidents as the numerator (rather than number of trucks) is to make the risk estimates somewhat lower.

Cowley questions whether it is appropriate to use the same denominator (traffic count, in this case) when analysing single- and multiple-vehicle accidents. He comments

> Although one expects SV accident numbers to be proportional to vehicle-distance, the derivation of MV accident rates is over-simplified because no account is taken of the mechanism of collisions. For example, MV collisions could be proportional to "potential conflicts" between vehicles. Thus, the 3 kinds of MV car/truck collisions, CC [car-car], CT [car-truck] and TT [truck-truck] might be respectively proportional to c2, 2ct and t2, derived from a (c + t)2 "product model", or to c(c-1), 2ct and t(t-1), derived from a "pairs sampling model". In addition, it is likely that SV and MV accident involvement rates are related in some manner. (p. 33)

The current study uses number of vehicles of that type as the denominator and does not attempt separate analyses of single- and multi-vehicle accidents. This constraint was necessary because of the small numbers of accidents in some cells of the data matrix.

APPENDIX SIX
RESULTS OF THE TIME-OF-DAY ANALYSES

Table A5.1. Total number of truck accidents (artics plus rigids) in each two-hourly period.

Highway	Time period (hours)											
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24
Princes West	1	2	1	4	6	3	1	5	5	8	1	4
Western	6	6	9	9	4	8	7	7	5	3	3	6
Calder	4	1	2	4	5	6	2	0	5	4	0	1
Hume	13	16	19	13	4	11	9	8	6	5	7	8
Murray Valley	3	0	3	2	4	8	5	3	6	4	2	2
Princes East	4	3	6	13	10	12	8	11	11	6	5	6

Table A5.2. Total number of articulated vehicle accidents in each two-hourly period.

Highway	Time period (hours)											
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24
Princes West	1	2	1	2	3	2	1	1	4	5	0	2
Western	5	5	8	7	2	4	3	2	3	3	3	6
Calder	4	1	0	1	2	1	2	0	2	3	0	0
Hume	12	15	17	10	2	6	5	6	5	5	7	6
Murray Valley	3	0	3	1	2	4	2	1	3	3	1	2
Princes East	1	1	4	9	5	9	2	4	7	3	3	4

Table A5.3. Total number of rigid vehicle accidents in each two-hourly period.

Highway	Time period (hours)											
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24
Princes West	0	0	0	2	3	1	0	4	1	3	1	2
Western	1	1	1	2	2	4	4	5	2	0	0	0
Calder	0	0	2	2	3	5	0	0	3	1	0	1
Hume	1	1	2	3	2	6	5	6	1	0	0	2
Murray Valley	0	0	0	1	2	4	3	2	3	1	1	0
Princes East	3	2	2	4	5	3	6	7	4	3	2	2

Table A5.4. The mean numbers of trucks per channel (artics plus rigids) in each two-hourly period. (Values are rounded to the nearest whole number)

Highway	Time period (hours)											
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24
Princes West	1	1	3	7	12	9	8	8	9	5	3	2
Western	49	37	23	24	29	30	32	36	42	40	44	57
Calder	6	6	10	21	26	21	18	17	16	14	11	9
Hume	55	73	90	84	88	86	79	96	102	84	91	79
Murray Valley	4	3	5	9	13	18	15	15	14	9	5	4
Princes East	11	10	13	27	43	48	47	46	33	22	16	10

Table A5.5. The mean numbers of articulated vehicles per channel in each two-hourly period. (Values are rounded to the nearest whole number)

Highway	Time period (hours)											
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24
Princes West	1	1	2	3	4	3	3	2	3	2	1	1
Western	42	32	19	15	12	11	14	18	25	30	37	49
Calder	3	3	5	6	6	5	6	5	6	7	5	3
Hume	47	62	74	61	45	40	38	49	55	53	70	68
Murray Valley	3	2	3	4	3	5	6	6	6	5	4	3
Princes East	8	7	7	8	10	13	12	12	8	9	8	6

Table A5.6. The mean numbers of rigid trucks per channel in each two-hourly period. (Values are rounded to the nearest whole number)

Highway	Time period (hours)											
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24
Princes West	0	0	1	4	8	7	5	5	6	3	1	1
Western	7	4	4	10	17	19	18	18	17	10	7	8
Calder	3	3	6	15	20	16	12	11	10	7	6	6
Hume	8	11	16	23	43	47	41	47	47	30	22	11
Murray Valley	1	1	2	5	10	13	9	10	7	3	2	1
Princes East	3	3	6	20	33	35	34	34	25	13	7	5

Table A5.7. Risk estimates for all trucks (articulated vehicles and rigid trucks).

Highway	Time period (hours)											
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24
Princes West	1.66	3.32	0.55	0.95	0.83	0.55	0.21	1.0	0.92	2.65	0.55	3.32
Western	0.74	0.98	2.37	2.28	0.84	1.62	1.33	1.18	0.72	0.45	0.41	0.64
Calder	3.43	0.86	1.03	0.98	0.99	1.47	0.57	0.00	1.61	1.47	0.00	0.57
Hume	2.00	1.85	1.79	1.31	0.38	1.08	0.96	0.71	0.50	0.50	0.65	0.86
Murray Valley	2.04	0.00	1.63	0.60	0.84	1.21	0.90	0.54	1.16	1.21	1.09	1.36
Princes East	1.25	1.03	1.58	1.65	0.80	0.86	0.58	0.82	1.14	0.94	1.07	2.06

Table A5.8. Risk estimates per two-hour period for articulated vehicles.

Highway	Time period (hours)											
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24
Princes West	1.08	2.17	0.54	0.72	0.81	0.72	0.36	0.54	1.44	2.71	0.00	2.17
Western	0.71	0.93	2.51	2.78	0.99	2.17	1.28	0.66	0.72	0.60	0.48	0.73
Calder	5.00	1.25	0.00	0.63	1.25	0.75	1.25	0.00	1.25	1.61	0.00	0.00
Hume	1.76	1.67	1.58	1.13	0.31	1.03	0.91	0.84	0.63	0.65	0.69	0.61
Murray Valley	2.00	0.00	2.00	0.50	1.33	1.60	0.67	0.33	1.00	1.20	0.5	1.33
Princes East	0.26	0.30	1.19	2.34	1.04	1.44	0.35	0.69	1.82	0.69	0.78	1.38

Table A5.9. Risk estimates per two-hour period for rigid trucks.

Highway	Time period (hours)											
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24
Princes West	0.00	0.00	0.00	1.21	0.90	0.34	0.00	1.93	0.40	2.41	2.41	4.82
Western	0.92	1.58	1.58	1.26	0.74	1.33	1.40	1.76	0.74	0.00	0.00	0.00
Calder	0.00	0.00	2.25	0.90	1.01	2.11	0.00	0.00	2.03	0.97	0.00	1.13
Hume	1.49	1.08	1.49	1.56	0.55	1.52	1.46	1.52	0.25	0.00	0.00	2.17
Murray Valley	0.00	0.00	0.00	0.75	0.75	1.16	1.25	0.75	1.61	1.25	1.88	0.00
Princes East	5.07	3.38	1.69	1.01	0.77	0.43	0.89	1.04	0.81	1.17	1.45	2.03

APPENDIX SEVEN
THEORETICAL BACKGROUND TO IN-VEHICLE FATIGUE COUNTERMEASURES

In this Appendix a summary of research underlying the development of in-vehicle fatigue countermeasures is presented. Various measures of driver fatigue are described and an attempt is made to indicate their advantages and disadvantages. The structure follows that of Chapter 4. The research into psychophysiological measures and measures of vehicle control behaviour which allowed the development of driver fatigue monitors is presented, followed by a description of reaction time measures of driver fatigue, the basis of reaction time devices to maintain driver alertness. A more detailed review of measures of driver fatigue can be found in Haworth, Triggs and Grey (1988).

Psychophysiological measures

In a discussion of the neurophysiological and psychological aspects of fatigue, Grandjean (1968), explained that humans possess an activating system which comprises both arousal and an inhibitory mechanisms. Sudden psychological events which may produce fear or excitement can stimulate the system, even if the person was currently feeling tired. This ability to respond to unexpected environmental changes can act to disrupt the progressive pattern of fatigue in an unpredictable manner, making it difficult to gain reliable baseline fatigue measurements. Therefore, physiological indices of fatigue, reflect not only changes in the functional capacity of the organism but also changes due to extraneous factors such as muscle tone and anxiety (Zinchenko, Leonova and Strelkov, 1985).

Many studies of driver fatigue have concentrated on psychophysiological responses. Research conducted by Lemke (1982) was based on the electroencephalogram (EEG) of the driver. Other research has used the electromyograph (EMG) to measure muscle activity or the electrooculograph (EOG) to measure eye movements (e.g., Wertheim, 1978).

Brown and Huffman (1972) measured the psychophysiological responses of heart rate (HR), rate of lateral eye movement, and rate of galvanic skin response. With the exception of HR, drivers' psychophysiological responses were found to differ significantly during different driving conditions. The findings also indicated that during daylight driving in heavy traffic, arousal levels were higher than night driving in moderately heavy traffic. Brown and Huffman's (1972) study demonstrated that psychophysiological measures can be sensitive to different driving tasks.

Riemersma, Sanders, Wildervanck and Gaillard (1977) measured heart rate (HR) during an eight-hour night-time driving task. They concluded that the decrease observed was due to adaptation to the task rather than fatigue as HR decreased in the early hours of the task and then levelled out. At the end of testing no effects were found on HR from lack of sleep. If fatigue affects HR then it would be expected that either lower arousal (identifiable by lower HR) or increased effort to counteract the effects of sleep loss (identifiable by increased HR) would be demonstrated after testing. As this was not found, it appears that HR does not predict changes in driving performance due to fatigue.

An advantage of using psychophysiological measures is that they provide readings that can be measured directly and quantitatively (Zinchenko, Leonova and Strelkov, 1985). However these provide direct measures of fatigue indicators only, rather than the fatigue phenomenon itself. Because there is baseline variability in psychophysiological measures (which may arise from muscle movement and activities associated with controlling a vehicle), the extent to which this interferes with readings would influence the effectiveness of a fatigue monitoring device. The effectiveness of these devices also depends on the extent to which the psychophysiological response that they measure is affected in a reliable manner by fatigue.

Researchers have distinguished several types of eye closure based on the velocity and duration of closure. Blinks are defined as closures of short duration, less than about 800 msec (Stern, Walrath and Goldstein, 1984). Nonblink closures take longer than 250 msec to initiate and the eye is usually closed for a period of seconds. Some studies of the effect of fatigue on eye closure have measured blinks and others have concentrated on the longer duration closures.

Fukui and Morioka (1971) measured eye closure using the 'blink method'. Blink value is derived by measuring the rotation speed at which a pattern can be recognised using rapid eye blinks. Fukui and Morioka found that blink value was lower during fatigued states than non-fatigued states. In contrast, several researchers have shown blink rate to increase with fatigue. Watanabe, Kogi, Onishi, Shindo and Sakai (1982) reported that blink rates of train drivers increased during long-duration, monotonous trips.

Studies of fatigue which have measured the frequency of long duration eye closures have produced more consistent results. Beideman and Stern (1977) found that blink duration increased over time in a simulated driving task but blink rate did not show the same effect. Goldstein, Walrath and Stern (1982, cited in Stern, Walrath and Goldstein, 1984) ran subjects in a discrimination paradigm for 128 minutes. From the first to the final five minutes of the task, mean blink duration increased significantly and the number of long duration closures increased. Similar findings were demonstrated in two 20-minute simulated driving sessions by Stern, Beideman and Chen (1976, cited in Stern et al., 1984). Bauer, Strock, Goldstein, Stern and Walrath (1985) examined the association between blinking and mental activities. Their study found that eyeblink and eyelid closure durations increased as the experimental task proceeded and attentional processes waned.

Measures of vehicle control behaviour

A German study (Lemke, 1982) has suggested that measures of vehicle control behaviour may provide more valid indices of driver fatigue than psychophysiological measures. Lemke showed that loss of precision in the control behaviour of drivers was correlated with an anterior displacement of the resting potentials in the EEG data. Because both EEG data and vehicle control activity were affected by fatigue, Lemke assumed that the EEG signals could be used to predict vehicle control behaviour. The reverse was found: control activity predicted EEG patterns. An implication of this finding is that a more effective fatigue monitoring device could be built with input from the controls (e.g., steering wheel, brakes), rather than from EEG measures.

Results from a number of studies can be used to judge which types of vehicle control behaviour produce valid indices of driver fatigue. Measures of steering patterns or the resultant lateral placement of the vehicle have been found to be valid measures of driver fatigue by O'Hanlon and Kelley (1977) and Riemersma, Sanders, Wildervanck and Gaillard (1977). Consistency of acceleration (Shaw, 1957), brake reaction time (Dureman and Boden, 1972; Mast, Jones and Heimstra, 1966) and speed maintenance (Riemersma et al., 1977) were not found to be good indices of driver fatigue.

Measurement of subsidiary reaction time

The research reported here is concerned with subsidiary reaction time, the latency of responding on a task performed concurrently with driving. Measures of reaction times of tasks involved in driving, e.g., brake reaction time, have not been found to be satisfactory measures of driver fatigue (Mast, Jones and Heimstra, 1966; Dureman and Boden, 1972).

Subsidiary reaction time (RT) during driving has been measured using response to auditory signals, (Lisper, Laurell, and van Loon, 1986), and visual signals (Brown, Tickner and Simmonds, 1970). A large body of research utilizing RT as a measure of fatigue has been conducted in the laboratories of Lisper in Sweden and Brown in the United Kingdom. These studies report a consistent finding that reaction time increases with hours of continuous driving, indicating that RT is a reliable index of fatigue (Brown, 1967; Brown, Simmonds and Tickner, 1967; Lisper, Dureman, Ericsson and Karlsson, 1971; Lisper, Eriksson, Fagerstrom and Lindholm, 1979; Lisper, Laurell and Stening, 1971; Lisper, Laurell and van Loon, 1986).

Laurell and Lisper (1976) found that RT increased over time only for subjects who were driving and not for subjects travelling as passengers or for subjects in a stationary vehicle, which suggests that RT measurement per se does not promote its own deterioration. Laurell and Lisper (1978) found a high correlation between RT and detection distances to roadside obstacles, indicating that RT is a valid index of fatigue.

The usefulness of RT monitors as indices of fatigue is also influenced by age and driving experience. Lisper, Laurell and Stening (1973) compared RTs of subjects with less than 5000 kilometres driving experience with those of professional drivers, on a 2.5 hour driving task. Their findings indicated that inexperienced drivers showed an increase in RT whereas experienced drivers showed a slight decrease in RT.

A fatigue monitor based on measuring the RT to an auditory or visual signal sounding an alerting signal if the RT was beyond a certain criterion time has the potential to be a useful fatigue countermeasure. Such a device could possibly include adjustment to the normal, unfatigued reaction time of the driver since there is some baseline variability (e.g., with age and experience) in such measures.