Centre for
Automotive Safety Research

Heavy vehicle road safety: Research scan

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CASR REPORT SERIES

CASR100

July 2011

Report documentation

REPORT NO.	DATE	PAGES	ISBN	ISSN
CASR100	July 2011	110	978 1 921645 37 2	1449-2237

TITLE

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Centre for Automotive Safety Research
http://casr.adelaide.edu.au/publications/researchreports

ABSTRACT

The number of registered heavy vehicles (HV) in Australia has risen 22% since 2005 and, with the national freight task projected to double by 2030, the number of HVs on Australian roads is set to continue to increase. In the 12 months to the end of June 2010 crashes involving heavy vehicles resulted in 239 fatalities while around one third of all work-related road crash fatalities occur within the freight industry. Heavy vehicle safety for both the trucking industry and the general community remains an important issue. In recognition of this the Australian Trucking Association has commissioned a research scan to develop a knowledge base that may be used to guide the strategic direction and development of effective outcomes in the area of heavy vehicle safety. The scan focussed on five key areas: factors associated with HV crashes, road and vehicle design, human and social factors, speed management and enforcement, and the effectiveness of accreditation schemes. This scan identified a number of gaps in knowledge and recommendations for future research were suggested in the areas of fatigue, seat belt use, traffic management, and technology.

KEYWORDS

Heavy vehicle, truck, safety, crashes, road safety

Summary

Trucks are a common sight on Australian roads, be it rural highways or the arterial roads of major cities and towns. Statistics from the ABS (2011) indicate that the number of registered heavy vehicles (HVs) in Australia has grown by 22% since 2005. Projections indicate that Australia's freight task is set to at least double by 2030; the number of HVs on Australian roads is set to rise in line with this. In the 12 months to the end of June 2010, HVs were involved in 194 crashes throughout Australia resulting in 239 fatalities. Furthermore, around one third of all work-related road crash fatalities occur in the freight industry. HV safety remains an important issue to address for the HV industry and the community. In recognition of this the Australian Trucking Association has commissioned a research scan in order to develop a knowledge base that may be used to guide the strategic direction and development of effective outcomes in the arena of heavy vehicle safety.

This scan focussed on five key aspects of HV safety:

- factors associated with HV crashes
- road and vehicle design
- human and social factors
- speed management and enforcement
- the effectiveness of accreditation schemes.

An overview of findings is provided below.

HV crashes

The most common types of HV crash were single vehicle crashes involving leaving the road or rolling over. The most common factors involved in HV crashes are speed, the mechanical condition of the vehicle (particularly brakes), and the characteristics of the load being carried (including overloading). Human factors such as fatigue, substance use, and driver distraction are more commonly identified for HV drivers who are responsible for a crash than those HV drivers who are not responsible for a crash.

Currently, leading road safety nations have adopted a systems based approach to road safety which is based on the principle that road users make mistakes and that the road system needs to better accommodate these mistakes when they occur. Governments will be using the Safe Systems approach to road safety when considering heavy vehicle road safety over the next decade.

Road and vehicle design

The horizontal alignment of curves and other design features of roads represent safety hazards for HV drivers. The provision of shoulder sealing is one way this issue may be tackled providing benefit not only for heavy vehicles but other vehicle types as well. Other risks can be addressed through vehicle design, particularly the use of on-board warning systems and crash avoidance technologies to improve the stability and control of the vehicle.

The design of HVs is such that they have high aggressivity, presenting a significant risk to other road users, and poor crashworthiness, presenting a risk to HV occupants. Improvement in either or both of these areas would produce safety benefits.

Human and social factors

Fatigue is an issue of primary concern for the HV industry, and particularly so for long haul drivers. A number of advancements in knowledge and management of fatigue have been made however, there is room for improvement.

The prevalence of substance use among HV drivers is generally comparable to rates observed in the general driving population throughout Australia, however the use of stimulant substances (such as amphetamines) is more common among HV drivers as they tend to be used to combat the effects of fatigue. Little is known with regard to HV drivers use of prescription medications to treat medical conditions, nor the effects of these on HV crashes.

Heavy vehicle drivers also have a higher risk of some general and mental health problems.

Speed management and enforcement

Speed is an issue for heavy vehicle safety. Low level speeding among HVs is more common than extreme speeding. The use of speed limiters and Intelligent Speed Assist technologies (ISA) offer safety benefits with regard to the management of HV speeds.

High visibility police enforcement operations effectively reduce speeds in targeted areas however, these effects are short lived once the operation has ceased. Speed cameras have been shown to effectively reduce crashes and lower average speeds on roads where they are installed.

Accreditation schemes

Evidence indicates accreditation schemes such as the National Heavy Vehicle Accreditation Scheme (NHVAS) and TruckSafe have improved the safety of the accredited organisations.

Overview and conclusions

A number of knowledge gaps were identified in order to provide direction for future research. Four key recommendations for future research were provided. These included research that:

- Improves the management of fatigue within the HV industry.
- Improve the use of seat belts among HV occupants.
- Evaluates the effectiveness of HV traffic management schemes under Australian conditions (mainly in relation to lane use and speed management).
- Evaluates the effectiveness of emerging HV safety technologies.

Contents

Acronyms

ABS	Australian bureau of statistics
ABS	Anti-lock braking system(s)
ACC	Adaptive cruise control
AFM	Advanced fatigue management
AVCSS	Advanced vehicle control and safety systems
BFM	Basic fatigue management
BITRE	Bureau of Infrastructure, Transport, and Regional Economics
BMI	Body mass index
CDL	Commercial driver's licence
CPAP	Continuous Positive Airway Pressure
DSL	Differential speed limit
DSRC	Dedicated short range communication
EBS	Electronically controlled braking system
ESC	Electronic stability control
ESP	Electronic stability program
EWD	Electronic work diary
FCW	Forward collision warning
FMCSA	Federal motor carrier safety administration
FMP	Fatigue management program
GPS	Global positioning system
GVM	Gross vehicle mass
GVWR	Gross vehicle weight rating
HGV	Heavy goods vehicle
HOS	Hours of service
HV	Heavy vehicle
HVDF	Heavy vehicle driver fatigue
IAP	Intelligent access program
ISA	Intelligent speed adaptation
ITS	Intelligent transport system
LCM	Lane change merge
LDW	Lane departure warning
LOC	Loss of control
LTCCS	Large truck crash causation study
LV	Light vehicle
MCMIS	Motor carrier management information system
NHTSA	National highway traffic safety administration
NHVAS	National heavy vehicle accreditation scheme
NTC	National transport commission
NTI	National transport insurance
NZHVBC	New Zealand heavy vehicle brake code
OApps	Oral appliances
OBM	on-board mass-monitoring
OOS	Out of service
PBS	Performance based standards
RSC	Roll stability control
RVS	Rearview video system
TFMS	Transitional fatigue management scheme
UPPP	Uvulopharyngopalatoplasty (a surgical procedure to change the shape of the pharynx)
USL	Uniform speed limit
VSS	Vehicle stability systems
WIM	Weigh-in-motion
YSC	Yaw stability control

1 Introduction

Trucks are a common sight on Australian roads, be it rural highways or the arterial roads of major cities and towns. Statistics from the ABS (2011) indicate that to the end of March, 2010 there were 536,247 registered trucks in Australia, an increase of 22.4% since 2005. In the 12 month period ending October, 2007 heavy vehicles travelled a combined total of 15,856 million kilometres with articulated trucks having the highest average kilometres driven of all vehicle types (see Table 1.1).

Table 1.1
Total (in millions) and average (in thousands) kilometres travelled to end of October, 2007 (Source: ABS, 2008)

	Total kms (x1,000,000)	Average kms (x1000)
Passenger vehicles	157,928	13.7
Motorcycles	1,905	3.7
Light commercial vehicles	37,385	17.1
Rigid trucks	8,644	22.0
Articulated trucks	6,929	93.2
Non-freight carrying trucks	283	14.2
Buses	2,097	31.6
Total	215,171	14.6

Indeed, heavy vehicles play an integral role in the transportation of freight throughout Australia. Since 1971 the Australian road freight task has increased by a factor of 6 reaching 184,072 million tonne-kilometres in October, 2007 (ABS, 2008), with current projections indicating this figure will at least double by the year 2030 (BITRE, 2011). It is clear that the number of heavy vehicles on Australian roads will grow proportionately with the increasing freight task.

Coinciding with the growth of the freight task and numbers of heavy vehicles are increases in numbers of other vehicle types on the road network including passenger cars and motorcycles. Table 1.2 shows the growth in ownership of all vehicle types from 2005 to 2010 as reported in the Australian Bureau of Statistics 2010 motor vehicle survey (ABS, 2011). The number of registered passenger vehicles has increased by 12.6%, motorcycle ownership rose by 56.5%, and the number of light commercial vehicles also rose by 21.2%, all since 2005. With such growth rates, improving road safety across the entire road network will continue to be a significant issue for the trucking industry as well as all other road users.

Table 1.2
Growth of registered vehicles from 2005 to 2010 (Source: ABS, 2011)

	2005	2010	% change
Passenger vehicles	10,896,410	12,269,305	12.6
Campervans	40,693	48,504	19.2
Light commercial vehicles	2,030,254	2,460,568	21.2
Rigid trucks	368,520	431,278	17.0
Articulated trucks	69,723	82,436	18.2
Non-freight carrying trucks	19,962	22,367	12.9
Buses	72,620	86,367	18.9
Motorcycles	421,923	660,107	56.5
Total	13,920,105	16,061,098	15.4

According to Safe Work Australia (2009) 41 of the 295 working fatalities (19%) recorded in the 2006-07 period were in the road freight transport industry. During this same period the rate of fatal injury among road and rail drivers was 25.1 per 100,000, the highest rate of fatality observed across all industries. Furthermore, the transport and storage industry also has the highest incidence of road crashes of all industries, contributing 45.6% of all work-related road crash fatalities, with the majority of these (76%) observed in road freight transport. Road crashes were also the greatest cause of fatality amongst this group (Safe Work Australia, 2009). Improving the safety of heavy vehicle operators is clearly a high priority.

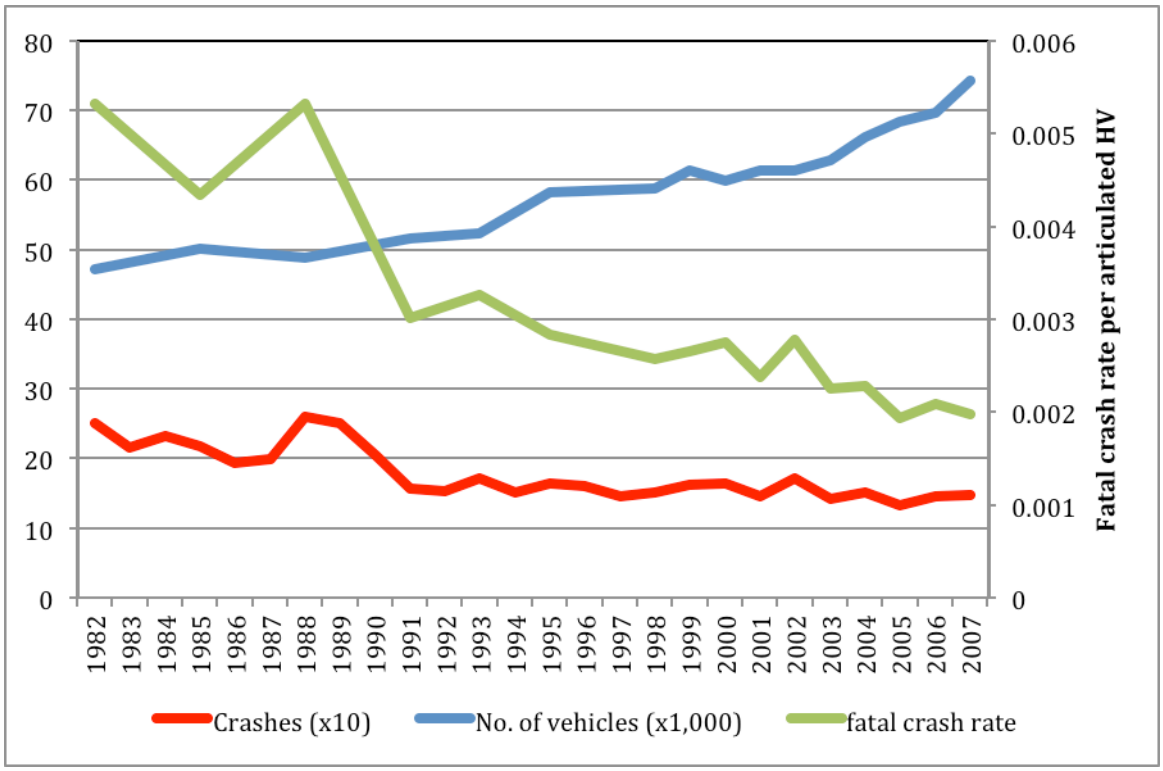
A study comparing the heavy vehicle safety performance of Australia's road transport industry to the USA, Canada, New Zealand, the UK, France, Germany, and Sweden (Haworth, Vulcan, & Sweatman, 2002) found that Australia's heavy vehicle fatality rate per kilometre travelled was 47% higher than the US and 39% higher than the UK, comparable to Germany and Canada, 20% lower than Sweden, 45% lower than France, and 55% lower than New Zealand. This study concluded that Australia's poorer performance in comparison to the US and the UK was largely due to Australian trucks doing less travel on divided and limited access roads. Truck speed limits may also have contributed to the higher fatality rate observed in Australia compared to the UK and US.

Statistics for road crashes involving heavy vehicles provided by the Bureau of Infrastructure, Transport, and Regional Economics (BITRE, 2011) indicate that in the 12 month period to the end of June 2010 a total of 160 fatalities were recorded from 130 crashes involving articulated trucks, with a further 79 fatalities from 64 crashes involving heavy rigid trucks. As such, a considerable proportion of the nation's road toll can be attributed to crashes involving heavy vehicles. It should, however, be noted that the majority of these crashes are brought about by the actions of the drivers of light vehicles (Craft, 2007; Hakkanen & Summala, 2001; Hanowski, Hickman, Wierwille, & Keisler, 2007). Regardless, the impact of crashes involving heavy vehicles is borne by the drivers involved and their families, the trucking industry, and other road users.

Figure 1.1 depicts the trends in heavy vehicle safety observed from 1982 to 2007. The red line shows that articulated heavy vehicle fatal crash numbers have remained relatively constant since 1991. However, considering the increase in the number of articulated heavy vehicles (the blue line) it is clear that road safety gains have been achieved despite increased exposure. This can be observed with the success of B-doubles, which carry almost 50% of the freight task and account for less than 30% of heavy vehicle crashes, compared to semi-trailers that account for 60% of heavy vehicle crashes and carry around 40% of the freight task. The most significant gains in heavy vehicle road safety over this period are attributable to mass road safety initiatives that have improved safety for all road users, particularly improvements to the road network (including divided highways and sealed shoulders), reduced speed limits, and improvements in vehicle design. Heavy vehicle specific measures that have likely contributed to further safety gains include the introduction of fatigue management procedures and regulations, and safety accreditation.

An organised, coordinated approach to heavy vehicle road safety amongst all stakeholders is necessary to ensure both the safety of drivers (indeed all road users), and the productivity of the trucking industry. In order to facilitate and inform such an approach it is necessary to have some understanding of existing knowledge and identify important areas where future research is required to fill existing knowledge gaps. This research scan is intended to develop a knowledge base that may be used to guide the strategic direction and development of effective outcomes in the area of heavy vehicle safety.

Figure 1.1
Trend in articulated HV crashes (x10), number of articulated HVs (x1,000) and fatal crash rate per number of articulated HVs 1982-2007 (source: ABS, 1995, 2000, 2005, 2007; ATSB, 2007; BITRE, 2010)



Safe systems approach

Many leading road safety countries are now using a systems based approach to road safety. In Australia, the Safe Systems approach has been adopted in the upcoming National Road Safety Strategy and has been adopted by road authorities in each state and territory.

The approach takes a global view of road safety and considers the interaction between people, the road environment and vehicles. The key principles of the Safe System approach includes the following:

- Human Factors: acceptance that people make mistakes and that the road system should accommodate these mistakes when crashes occur.
- Human Frailty: the human body can only tolerate a certain amount of force before serious injury or a fatality can be expected in a crash.
- Forgiving Designs: the roads that we travel on, the vehicles we travel in and the speeds that we travel at need to be more forgiving of errors by road users.
- Shared responsibility: everyone has a responsibility to use the road safely and professionals have a responsibility to design, manage and encourage the safe use of the transport system.

Governments will be considering heavy vehicle road safety in this context over the next decade.

1.1 Organisation of the report

Seven key areas of interest have been identified by the ATA. These are:

- Heavy vehicle related accidents and causal factors
- Sleep science and fatigue management
- Road and vehicle design, including rest areas
- Speed management
- Human and social factors influencing heavy vehicle road safety, including heavy vehicle driver licensing
- Effectiveness of industry accreditation schemes
- Heavy vehicle interaction with other transport modes

There is a degree of overlap in the subject matter to be covered across each of these areas. The report was therefore structured to address these seven topics in five chapters. The *interaction of heavy vehicles with other transport modes* has been merged with the *road and vehicle design* topic, while *sleep and fatigue management* is addressed within the *human and social factors* topic. The structure for the report is shown in Table 1.3.

1.2 Presentation of results

The results of the research scan are presented in a tabular format. Each table identifies the author(s) of the publication, the publication type, the public availability of the publication, a brief description of the research involved, and concise summaries of the research findings. The tables are accompanied by a brief discussion of overall findings for each section as is a discussion of identified research gaps.

Table 1.3
Topic structure and examples of subject matter

Topic	Area
HV accidents: causal factors and characteristics	
	Speed
	Fatigue
	Seat belts
	Road infrastructure
Road & vehicle design	
	HV-other transport interaction
	Delineation
	Road condition
	Rest Stops
	Lane capacity
	Traffic management
	Underrun protection
Human & social factors	
	Sleep/fatigue
	Substance use
	Licensing schemes
	Fitness for duty
	Distraction
Speed management	
	Intelligent Speed Adaptation (ISA)
	Enforcement
Effectiveness of accreditation schemes	
	NHVAS
	TruckSafe
	WA heavy vehicle accreditation scheme

Note: items in italics indicate original topics that have been incorporated into other areas of the report

2 Research scan methodology

Heavy vehicle and road safety literature published in Australia and internationally were reviewed for each of the topics to be covered by the report. Focussing on research conducted within the last ten years ensures that the report considers the latest and most up to date knowledge available. Where necessary relevant research outside of the heavy vehicle or road safety fields were also incorporated to ensure a comprehensive coverage.

The literature search focussed on the key issues identified for each topic with search strategies customised accordingly. The literature search included a search of the Centre for Automotive Safety Research's extensive road safety library and also includes searches of the following databases and indexes:

- **Australian Transport Index (ATRI)** - Road transport resources. Subjects: road safety, traffic accidents, heavy vehicles, freight, traffic engineering, vehicle design, road design, human factors, speed and speed limits.
- **Transport** - Transport resources. Subjects: road safety, traffic accidents, heavy vehicles, human factors.
- **CASR library catalogue** - A collection of over 25,000 items Subjects: road safety, vehicle safety, vehicle design, human factors, speed, licensing.
- **Academic Search Premier** - A Multi-disciplinary database.
- **PsycInfo** - American Psychological Association (APA) database. Subjects: behavioural science, human factors.
- **Informit** - A Wide range of databases. Subjects: health, business, humanities, social sciences.
- **Compendex** - A Scientific and technical research database. Subjects: engineering.
- Internet search engines Google and Google scholar were also used to locate relevant materials.

The search also included the following materials: peer reviewed journal articles, published reports, technical papers, conference proceedings, and any relevant electronic materials.

Websites of key trucking and road safety organisations from Australia and internationally were also searched for relevant reports and other publicly available publications relevant to the aims of the research scan. These included:

- The Australian Trucking Association;
- Austroads;
- The National Transport Commission;
- The National Highway and Traffic Safety Association (US);
- The Federal Motor Carrier Safety Administration (US).
- Various Road Safety Research Organisations including Monash University Accident Research Centre, The George Institute
- State Road Authority websites

Key words

To identify research relevant to heavy vehicle road safety key words relevant to each area were identified and used. All searches were conducted to return results for both heavy vehicles and trucks. Examples of key words used in the present study are provided in Table 2.1.

Table 2.1
Examples of key search terms

Topic	Search terms*
HV accidents: causal factors and characteristics	
	Accident or crash
	Accident type
Road & vehicle design	
	Shoulder
	Roadside
	Median
	Barrier
	Rest stop
	Road design
	Vehicle design
	Electronic stability control
Human & social factors	
	Sleep and fatigue
	Fatigue management
	Substance and drug use
	Licensing schemes
	Fitness for duty
	Distraction
Speed management & enforcement	
	Intelligent Speed Adaptation (ISA)
	Enforcement
	Speed
	Speed management
Effectiveness of accreditation schemes	
	Accreditation scheme
	TruckSafe
	National heavy vehicle accreditation
General terms	
	Evaluation
	Technology
	Effectiveness
	Review

* All search terms used in conjunction with the terms “heavy vehicle” and “truck”

Limitations of the scan

Whilst every effort was made to identify and obtain the largest amount of heavy vehicle relevant research as possible, due to time constraints it is possible that some relevant materials have not been included.

3 Heavy vehicle crashes

This chapter addresses the characteristics of heavy vehicle crashes, including the causal factors, and factors that contribute to the death or injury of the people involved. For example, not wearing a seat belt will not of itself cause a crash however, failure to do so greatly increases the risk of injury or death in a crash. The most commonly researched factors with regard to heavy vehicle crashes are speed, driver factors (such as fatigue, substance use, attitudes, etc.), seat belt use, infrastructure (e.g., road design, condition, and alignment), vehicle factors (e.g., mechanical condition, type, load, and configuration), and issues related to vehicle control. Research regarding heavy vehicle crashes is summarised in Table 3.1.

Many studies highlight that where multiple vehicle crashes between trucks and passenger vehicles are involved, the heavy vehicle driver is often not at fault. Current international best practice in line with Safe Systems approaches suggest that efforts for improved HV safety are best served by identifying ways to reduce the number of heavy vehicle crashes irrespective of who is to blame. That is, measures that improve safety for all road users also improves safety for heavy vehicles (e.g. sealed shoulders).

Evidence regarding the characteristics and causal factors for heavy vehicle crashes also revealed the following:

- The most common truck crashes are associated with single-vehicles leaving the road.
- Excess speed and driving too fast for conditions are a common feature of HV crashes.
- The mechanical condition of trucks, particularly brake problems, is related to the risk of a truck crashing.
- Crashes where a HV leaves the lane, leaves the road, or rolls over are also associated with control issues.
- Aggressivity of heavy vehicles and greater mass play a key role in the injuries of the occupants of other vehicles and vulnerable road users (i.e., pedestrians, cyclists, and motorcyclists).
- The crashworthiness of trucks is generally poor due to poor cabin integrity in rollover and crashes where the truck hits a fixed object.
- Infrastructure including road design and condition are also important factors in HV crashes.
- The majority of fatal heavy vehicle crashes happen on highways and during daylight under favourable weather conditions.
- Younger truck drivers up to the age of 27 appear to have the greatest risk of crashing.

Table 3.1
Heavy vehicle crashes: Factors related to crash causation and/or driver injury or fatality

Authors	Type	Availability	Research	Factors						
				Speed	Driver	Seatbelts	Infrastructure	Vehicle	Control issues	Other
Brodie, Bugeja, & Ibrahim (2009)	Journal article	Public	Review of Coroners' files of heavy vehicle driver fatalities from 1999 - 2007	Excessive or inappropriate speed	Substance use	Non-use of restraints			Leaving road out of control	
McKnight & Bahouth (2009)	Journal article	Public	Analysis of information form investigated truck roll over crashes	Inappropriate speed	Inattention (including distraction) and Fatigue		Road surface and intersections	Load and brake condition	Oversteer, understeer, overcorrecting errors, and minor control errors	
Brodie, Bugeja, & Ibrahim (2010)	Journal article	Public	Examination of Coroners' recommendations on fatal heavy vehicle crashes				Comments to address road environment factors			
Tziotis, Pyta, & McLean (2009)	AustRoads report	Public	Site investigation of a sample of Australian and New Zealand locations of multiple heavy vehicle crashes				Intersections - visibility, delineation, insufficient signage or advisory, unsealed shoulders, roadside hazards, and lack of adequate safety barriers Road segments - poor surface condition, unsealed shoulders, visibility for overtaking, lack of adequate signage, and roadside hazards within the clear zone (e.g., trees, poles, & culverts)			
Styles, Mabbott, Roberts, & Tziotis (2008)	AustRoads report	Public	Analysis of crash data, inspection of heavy vehicle crash sites, literature				Road design - alignment, signage, lane capacity, clear zones, overtaking			

			review, and stakeholder workshops to identify key factors in heavy vehicle crashes				lanes, level crossings, signalised intersection clearance times, and off-street loading/unloading facilities			
Federal Motor Carrier Safety Administration (2006)	Report	Public	A sample of large-truck fatal and injury crashes investigated from 2001 - 2003 at a number of sites across the US.	Inappropriate speed	Fatigue, driver recognition and decision errors (however these issues were more common amongst drivers of passenger vehicles)			Brake problems		Adverse weather conditions and changes to traffic flow
Park & Jvanis (2010)	Journal article	Public	A case control study of 231 truck (and 462 matched controls) crashes from 2004.		Crash risk was associated with hours of driving with increases of 50-260% compared to first hour of driving					Crash risk of non-sleeper operations associated with multiday driving. Crash risk of sleeper operations associated with hours of driving
Korkut, Ishak, & Wolshon (2010)	Journal article	Public	Analysis of traffic and crash data for an elevated section of rural highway in southern Louisiana.	Speed, speed variance, and differences between truck and car speeds were positively correlated with crash rates			Prohibiting trucks from using left lane (US) with a speed limit of 55 mph in conjunction with a 60 mph limit for cars on a four lane rural freeway has road safety benefits.			Violation of lane restriction and lane occupancy were positively correlated with crash rates
Blower, Green, & Matteson (2010)	Journal article	Public	Examination of the link between mechanical condition of trucks and crash involvement using data from the Large Truck Crash Causation Study (LCTSS)					55% of vehicles in the LTCCS had one or more mechanical violations, 30% had at least one out-of-service condition. Violations in		

								brake and lighting systems were the most frequent mechanical failures. Hours of service violations and log out-of-service violations increased likelihood of precipitating a crash by 2 and 2.2 times respectively. Brake violations increase odds of a truck being the striking vehicle by 1.8 times for rear-end and cross-path crashes.		
Hakkanen & Summala (2001)	Journal article	Public	A study of fatal 2-vehicle crashes involving trucks and surveys of 251 long-haul truck drivers regarding factors that contribute to crashes		16% of truck drivers involved in crashes were responsible for the crashes. Factors that increased the likelihood of being responsible for the crash included younger age and driving at night. 13% of drivers had driven for periods over the prescribed 10 hours, 4% were tired prior to the crash, and 2% had fallen asleep before the crash. Accidents were					

					viewed as being caused by other drivers. Truck drivers were more likely to report fatigue as a causal factor if they had previously experienced fatigue problems.					
Zhu & Srinivasan (2011)	Journal article	Public	Analysis of factors affecting the injury severity of large truck crashes using data from the LTCCS.		Driver factors increasing severity of crash included: distraction (truck drivers), alcohol use (car) and emotional factors (car).		Head on and intersection crashes more severe than crashes on multi-lane highways			
Zhu & Srinivasan (2011)	Journal article	Public	Models factors that contribute to the severity of crashes involving tucks and cars.		Car drivers aged over 55, or who have used drugs or alcohol have an increased risk of severe injury in truck-car crashes. Injury severity increases for car drivers in crashes where truck drivers have used alcohol.		For truck drivers crashes on "non-junction" parts of highways are less severe than intersections and junctions.	For truck drivers rear end crashes with cars produce least severe injuries and head on collisions with cars more serious than other truck-car crashes.		Peak morning traffic increases injury severity for truck drivers. Collision with a fixed object has a high severity for truck drivers. Single truck roll-over crashes are more serious than multi-truck crashes.
Bjornstig, Bjornstig, & Eriksson (2008)	Journal article	Public	Examines the incidence of car-truck collisions in Sweden.		Among car drivers killed in collisions with trucks suicide was indicated in 4%, a rate which doubled for car drivers who crashed into trucks. 4% of car drivers killed had BACs over the legal limit.		Crashes into trucks generally occurred on 70-90km/h two-lane roads			Crashes into trucks generally occurred during the daylight, in winter, and on workdays.

Campbell (1991)	Journal article	Public	Examines the association between driver age and involvement in large truck crashes		Fatal accident involvement was found to increase with decreasing driver age. Drivers under the age of 21 were 6 times more likely to be involved in fatal crashes than other drivers. This association was not due to other factors related to crash involvement.					
Young & Liesman (2007)	Journal article	Public	Seeks to correlate overturning freight vehicle crashes with wind speeds measured at nearby weather stations in the US state of Wyoming							Local wind speeds predicted the likelihood of an overturning crash. Weather station data can also be used to predict overturning crashes.
Lisa, Lyndall, & Elias (2009)	Journal article	Public	Describes the nature, extent, and contributory factors of 61 fatal heavy vehicle crashes in Victoria between 1999-2007.	One third of fatally injured drivers were travelling at excessive or inappropriate speed	Stimulant or cannabis use was detected for one in six fatally injured drivers. In 27 cases where medical history was known 20 drivers were found to have significant medical conditions.	Non use of seat belts in 17 of the 25 cases where seat belt use was known.			One third of crashes were single vehicles leaving the road on a straight section of road.	
Blower & Matteson (2009)	UMTRI Report	Public	Presents statistics for trucks involved in crashes throughout the United States for 2007.	Excessive speed identified in 9% of crashes.	For truck drivers: 2% had been drinking alcohol. Drug use was reported for 1%. 2% were reported		80% of crashes occurred on highways.	36% of crashes involved rigid trucks, the remaining 64% were articulated.		80% of crashes occurred on dry roads. Two thirds of crashes occur in rural areas and

					as drowsy or asleep prior to the crash. 6% of crashes were attributed to inattention, 4% a failure to yield, and <1% using mobile phone.					during daylight hours. 85% of crashes occurred in "normal" weather. In 11% of crashes the other vehicle had crossed the centre line and struck the truck head on.
Federal Motor Carrier Safety Administration (2010)	Report	Public	US statistics of large truck crashes for 2008.	Driving too fast for conditions or at excessive speed was the second most common factor for truck and passenger vehicle drivers.	<u>For truck drivers:</u> Driver factors implicated in 68% of single vehicle and 30% of multiple vehicle crashes. <u>For passenger vehicle drivers:</u> Driver factors implicated in 85% single vehicle and 55% multiple vehicle crashes.	11% of truck drivers were not wearing a seat belt			Failure to stay in lane was the most common factor for both truck driver and passenger vehicle drivers.	20% of fatal and 17% of injury crashes were single-vehicle crashes. 64% of fatal crashes occurred on rural roads. The majority of all crashes occurred on a weekday. 33% of fatal and 24% of property crashes occurred at night.
Sullivan (2005)	UMTRI report	Public	Examines the factors that influence truck involvement in night time crashes.		Younger drivers had a lower dark/light ratio in night time fatal rear end crashes than did older drivers.					Dark/light odds of crashing were greater in rural compared to urban areas.
Sullivan & Flannagan (2004)	UMTRI report	Public	Examines the influence of lighting conditions on rear end crashes with trucks.							Rear end crashes between any vehicles were twice as likely during night. Fatal rear end crashes involving a struck truck were 9 times more likely in

										darkness than in light.
Sweatman, Ogden, Haworth, Corben, Rechnitzer, & Diamantopoulou (1995)	FORS report	Public	Research into the type, severity, and causes of truck crashes in urban areas.		Deficiencies in driver, rider, and pedestrian behaviour significantly contribute to causes of crashes.		Highlights the importance of the traffic engineering design of controlled and uncontrolled intersections.	Design of truck needs to be addressed to reduce aggressivity and improve drivers' field of vision.		
Rechnitzer (1993)	MUARC report	Public	Research to establish the causal factors that contribute to high levels of fatalities and injury arising from crashes involving heavy vehicles.					Differences in mass and rigidity means cars need to absorb more energy; car occupants also experience greater velocity change. Differences in size and height allows smaller vehicles to underrun trucks causing significant intrusion. Car occupants hitting rigid truck structures or car intrusion causes head and chest injuries. Unguarded truck wheels are a hazard for pedestrians and cyclists.		
Craft (2007)	FMCSA Tech brief	Public	Describes the incidence of rear-end crashes involving large trucks that are struck by other cars		Alcohol use by other drivers in rear end crashes is much higher than among truck drivers			Where a truck is the striking vehicle the causal factors of defective or		Trucks strike other vehicles in the rear more often than they are struck.

			or are the striking vehicle.		for striking and struck vehicles			poorly adjusted brakes are twice as likely to contribute to a rear end crash compared to when other vehicles strike a truck.		However, in fatal crashes trucks are struck more often by other vehicles. Around half of fatal crashes where another vehicle strikes the rear of a truck occur in dark but lighted conditions.
Evans, Batzer, & Andrews (2005)	Conference paper	Public	US evaluation of truck rollover crashes from 1994-2002 using FARS data.					Poor structural integrity during rollover is a primary cause of death for drivers of large trucks.		
Khorashadi, Niemeier, Shankar, & Mannering (2005)	Journal article	Public	Examines the differences between urban and rural driver injuries involving large trucks using California accident data.		In crashes where drugs or alcohol were identified as a primary cause of the crash, risk of severe/fatal injury increased by 250% in rural and 800% in urban areas.			In rural crashes involving articulated trucks the risk of severe/fatal injury increased by 26% relative to crashes involving rigid trucks.		Speculation that differences between urban and rural injury severities may be attributable to the different perceptual, cognitive and response demands on drivers in rural vs urban areas.
Imberger, Styles, & Walsh (2009)	Conference paper	Public	An analysis of Victorian truck rollover crashes using data from VicRoads crash information system and NTI for the period 2003-2007.	41% of crashes involved inappropriate speed (NTI).	30% involved fatigue (NTI); 25% met criteria for a fatigue related crash (VicRoads).	60% of drivers killed were not wearing a seat belt.	47% occurred on bends with the majority in 100 km/h zones (VicRoads).	60% of rollovers involved semi-trailers & 23% involved B-doubles (NTI); Two thirds of rollovers involved semi-trailers (VIcRoads). Dry loads were involved in the		10% of crashes were rollovers (VicRoads). 86% of rollovers were single vehicle crashes (VicRoads).

								greatest number of rollovers accounting for 36% (NTI).		
McLean (2009)	Conference paper	Public	Categorises the lead-in path characteristics of a representative accident sample set of articulated single vehicle loss of control crashes on curves.				Negotiating relatively narrow windy roads. Negotiating long sweeping curves.		Negotiating alternate lock curve sequences. Negotiating a curve while applying, and post, high torque application of steering.	
Kharrazi & Thomson (2008)	Conference paper	Public	An analysis of heavy truck loss of control crashes based on the LTCCS.				A road sloping down was more often associated with loss of control than a road sloping up.		Three critical manoeuvres were identified as the most common causing loss of control: negotiating a curve, avoidance manoeuvres, and road edge recovery.	Dry roads were present in 75% of LOC crashes, however wet roads were associated with more than 50% of cases with yaw instability.
Shearer (2002)	Conference paper	Public	A paper outlining issues relevant to heavy vehicle road safety in remote areas.	Speed contributes to heavy vehicle crashes in remote areas.	Fatigue and driving hours contribute to crashes in remote areas. Drivers' attitudes towards safe driving are also an issue.	Failure to wear seatbelts is an issue in crashes in remote areas.	Road conditions contribute to crashes in remote areas.			
Hassall (2002)	Conference paper	Public	Examines the incidence and characteristics of urban truck crashes from 1990 to 1999.	Most truck related fatal crashes occur in low speed zones (<60km/h); the truck is responsible for the crash in around one third of incidents.			50-58% of urban truck crashes happen in locations other than intersections.			The minority of truck related fatal crashes occurred in urban areas. 33% of rigid truck crashes and 23% of serious injury crashes involving trucks occur in urban areas.

										Nearly 80-90% of urban truck related accidents occur between 6am and 8pm. Passenger sedan and pedestrian behaviour require considerable attention within the urban environment. Urban articulated truck combinations increased their numbers and urban travel by 23% and 37% respectively; urban articulated fatalities decreased over the period.
Curnow (2002)	Conference paper	Public	Examination of heavy vehicle crash data for the year 2000 from the NTI and the ATCD databases.	10% of articulated and 3% of heavy rigid trucks were probably speeding at the time of the crash.	10% of articulated truck drivers and 2% of heavy rigid truck drivers may have been suffering from fatigue.	Two thirds of articulated truck drivers and 50% of heavy rigid truck drivers killed in single vehicle crashes were not wearing a seat belt.	Crashing at an intersection was the most common crash factor.		For crashes occurring at outward trip distances of 201-300km, 410-500km, and 701-800km the most common type of crash involved the truck running off the road.	25% of heavy truck crashes were single vehicle crashes. Two thirds of heavy truck crashes with other vehicles involved passenger cars and 10% involved light trucks. Articulated truck crashes were distributed evenly throughout the day while heavy rigid truck crashes occurred between

										6am and 6pm.
Williamson, Irvine, & Friswell (2003)	Conference paper	Public	Examines patterns of HV crashes in NSW between 1996-2000.	Higher proportions of HV crashes occurred on higher speed roads.			Higher proportions of crashes occurred in country areas.	Articulated heavy trucks, B-doubles, and roadtrains showed the highest rates of crashes per registered heavy truck.	Where the HV was deemed responsible for the crash the main type of crash was off path on curve or pedestrian related.	A higher proportion of crashes occurred between midnight and dawn.
Driscoll (2011)	NTI Major accident investigation report.	Public	A review of heavy truck crashes with an aggregate cost greater than $50,000 managed by the National Claims Centre of the NTI.	32% of incidents could be attributed to inappropriate speed.	The number of Fatigue related crashes reduced by 50%			B-doubles carry 46% of the freight task and account for around 30% of all major truck crashes. Semi-trailers were involved in 60% of major crashes but		70% of crashes involved no other vehicle. In fatal crashes involving another vehicle the other driver was determined to be at fault in 82% of incidents. A 27% reduction in serious truck crashes since 2002 was reported.

3.1 Gaps in research

It is evident that factors contributing to heavy vehicle crashes resulting in serious injury or death to any occupants involved have been well documented. However, technologies continue to evolve leading to advancements in vehicle and road design. As such the continued evaluation of factors that contribute to HV crashes is warranted to ensure that strategies to reduce heavy vehicle crashes address the relevant issues.

Evidence also indicates that when other vehicles are involved in HV crashes, the HV driver is often not deemed at fault. Where HV drivers are at fault, including single vehicle crashes, driver issues such as alcohol and substance use, fatigue, and inattention are common factors. One possible interpretation of these statistics is that there is potentially a sub-set of heavy vehicle drivers that are inherently more dangerous on the roads than the wider HV driver population. An interesting line of research derived from this interpretation would seek to investigate this further. Such research should potentially seek to develop a profile of high risk heavy vehicle drivers that might consider a number of driver and vehicle characteristics; characteristics of the operations for which high-risk HV drivers work may also be worthy of further investigation. Benefits of this research could include:

- Provide intelligence to inform enforcement and compliance practices.
- Identify drivers and operations that may require particular attention with regard to HV safety.
- Identify targets for intervention within the high risk HV driver's environment. These may include management aspects of the transport operation in which they are employed, characteristics of the vehicle (such as age, maintenance record, safety features, and type of vehicle), and the characteristics of the work environment (e.g., working hours, trip length, etc.).

Other aspects of heavy vehicle safety that appear to be overlooked are heavy vehicle crashes of lower severity and near misses. The availability of data relevant to such crashes is not available from traditional sources and some other approach to investigation would be required. Understanding factors that influence heavy vehicle crashes with minor severity outcomes may have some inherent value for improving safety and productivity for trucking companies.

4 Road and vehicle design, and infrastructure planning

This section addresses research regarding the safety implications of the design of roads and vehicles. It addresses areas such as road infrastructure (engineering treatments, line markings, and roadside hazard), road features (e.g., intersections, road alignment, road condition), traffic management (signage, route access), vehicle features (underrun protection, safety technologies, mass efficiency), and heavy vehicle interactions with other road users.

As identified in section three, the design of roads and road infrastructure can have important implications for the involvement of heavy vehicle in crashes. Furthermore certain design aspects of heavy vehicles are related to a heavy vehicle's risk of crashing and the outcomes of that crash for both the heavy vehicle occupants and other people involved in the crash as occupants of a passenger vehicle, motorcyclist, cyclist, or pedestrian.

Table 4.1 outlines research relevant to the design of roads and infrastructure that have important safety implications for heavy vehicles. Some of the key findings from this research include:

- Road design and infrastructure could be improved to better accommodate heavy vehicles, particularly along freight routes.
- Road design should consider factors such as horizontal alignment and the impact of heavy vehicles on the road surface.
- Simple measures such as sealing shoulders along freight routes are a cost-effective means of improving safety.
- The use of truck climbing lanes and lane restrictions for heavy vehicles provide some safety benefits without major disruptions to overall traffic flow.
- Rest areas throughout Australia are inadequate and do not meet established standards with regard to location and the facilities that they provide.
- Freight networks in urban areas could be improved to better accommodate heavy vehicles.

Table 4.2 provides an overview of research relevant to the safety implications associated with the design of heavy vehicles. Key findings of this research include:

- The crashworthiness of truck cabins is generally poor due to the lack of protection afforded during roll over crashes. Cabins also fail to prevent objects intruding into the cabin space.
- The loading of heavy vehicles directly influences the dynamic stability of the vehicle.
- The enforcement of design standards could be improved, particularly with regard to underrun protection.
- Australian and international research indicates that there are a range of braking options that improve the braking performance and safety of heavy vehicles.
- There are a number of design options for increasing the roll stability of heavy vehicles.
- Design features such as underrun protection that exploit the crashworthiness of passenger vehicles reduce the severity of some crash types for other road users, including cyclists.
- Improving the visibility of heavy vehicles, particularly side-on visibility, under poor lighting conditions improves safety for other road users.

Table 4.3 summarises research relating to the benefits, use, or development of technologies that have the potential to improve the safety of heavy vehicles. Findings indicate:

- A number of technologies are available that have demonstrated benefits with regard to reducing the risk of a range of crash types including:
    - intelligent speed adaptation (ISA)
    - weigh-in-motion (WIM)
    - electronic stability control (ESC)
    - roll stability control (RSC)
    - antilock braking systems (ABS)
    - warning devices for rollover, collision, and lane departure.
- Intelligent transport systems (ITS) are improving safety for all road users by controlling, amongst other things, route access, speed limits, and traffic signal timing.
- An emerging ITS technology with large potential for all road users involve Digital Short Range Communications (DSRC) which allow vehicles to communicate with each other or the road infrastructure.
- Manufacturers are increasingly fitting enhanced safety features to heavy vehicles; the penetration rate of these features in the heavy vehicle fleet is more rapid than that of the general vehicle fleet.
- Technology can be used to improve safety and compliance. There is potential for the collected data to be used for traffic management.
- Driver acceptance of new technology and aids is an important issue for consideration.

Table 4.4 outlines research relevant to safety issues arising through the interaction between heavy vehicles and other vehicles. One of the major safety issues associated with heavy vehicle and other vehicle interaction are the differences in size and mass. Heavy vehicles with higher mass pose a higher risk of injury to most other road users. Naturalistic observations of heavy vehicle-light vehicle interactions suggest that the majority of safety-related (i.e., crashes and near misses) interactions appear to be initiated by the drivers of light vehicles.

Table 4.1
Road and infrastructure design implications for heavy vehicle safety

Authors	Type	Availability	Research	Findings
Chen, Chen, & Wu (2011)	Journal article	Public	Study of historical data for single vehicle truck crashes on a "typical mountain highway" in Colorado.	Adverse road conditions contributing to crashes on mountain highway included icy road surface, windy conditions, and graded curves.
Rumar, Sivak, Traube, & Miyokawa (1999)	UMTRI report	Public	Examination of the visibility of retroreflective pavement markings from trucks and cars.	Higher mounted headlights increased the distance of detection, implying that such pavement markings are more visible to truck drivers than car drivers.
Alvarez (2007)	FMCSA Tech brief	Public	A synthesis of literature regarding heavy vehicle interactions with highways.	Where steep upgrades reduce truck speed by 16km/h, truck climbing lanes should be considered. Long steep downgrades may lead to overheated brakes and a reduced ability to decelerate. The US provides warning signs and brake check areas, warning signs, and emergency escape ramps. Intersection features that need to be considered based upon the presence and frequency of heavy vehicles include kerb return radii for right turns (US), storage lengths for turn lanes, median widths on highways, and offset between opposing left-turn (US) lanes. Most evaluations of safety strategies that restrict trucks to only the right lane (US) show no positive or negative safety effects for such restrictions. The height of heavy vehicles can obscure highway signs to other road users. This has been overcome by including advance warning signs, and placement of signs overhead and on both sides of highways. Yellow light and red light clearance timing at light controlled intersections is an important consideration for trucks.
Smith, Baron, Gay, & Ritter (2005)	FMCSA report	Public	Report identifying the issues relevant to the provision of real-time information on parking availability to truck drivers on the road. Also outlines, to some extent, how truck drivers make use of different parking options.	The 4 areas most often used by truck drivers were public rest areas, privately owned truck stops, other private locations (e.g., loading docks), and the roadside. Truck stops were generally preferred for overnight rests and public rest areas for short naps. Desired attributes of long-term rest locations include food, fuel, restrooms, phones, showers, convenience to the highway, and well-lit parking areas. Surface evaluation of space availability versus demand suggests adequate provision of parking, however it was also noted that a number of regions do not have spacing sufficient to meet the demand. Lack of parking spaces is an issue for drivers seeking to maximise productivity by driving as far as possible under hours of service rules only to have no legal or suitable parking available to them. These drivers often stop on the side of the road creating potential safety hazards for themselves and other road users.
Geoff Anson	Austroads	Public	Examines the potential of using locations in industrial areas for	Such a strategy should be used to supplement rather than provide an

consulting and InfraPlan (Aust) (2010)	report		heavy vehicle parking in order to supplement the provision of roadside rest areas.	alternative to existing roadside facilities. Available options include on-street parking using existing council controlled roads, and off-street parking making use of privately owned spaces, or the development of new areas. Due to a number of administrative and technical reasons there is limited potential to use locations in industrial areas for parking heavy vehicles.
Su & Luk (2006)	Austroads report	Public	An investigation of the existing and future vehicles fleet mix in order to improve the level of service to freight, public transport, and emergency vehicle road users. Utilises data from the ABS Survey of Motor Vehicle Use.	Freight vehicles accounted for 17% of total vehicle kilometres travelled in all capital cities in 2004. Freight vehicles need to be properly managed in urban traffic systems due to the size and growth of the freight task. Available measures to improve level of service for road freight operations include changing land use regulations, multi-modal supply chain management, and various freight ITS measures.
Ramsay & Prem (2000)	Austroads report	Public	A report outlining the assessment of route suitability for heavy vehicles	The lane width requirements for trucks is based on vehicle configuration, length, and the road crossfall profile. Each state and territory has produced a network of routes that are suitable for four different classes of vehicle: general access, B-double, and road train types 1 & 2. Issues that should be considered in route assessments include: dimensional capacity, road safety, railway issues, community concerns, environmental issues, geometry, structural capacity, traffic conditions, operational issues, and future development.
Han, Green, Cairney, & Luk (2010)	Austroads report	Public	A report on measures for managing the safety of heavy vehicles at passive and active railway level crossings. Heavy vehicle crashes at level crossings are reviewed. Measures to mitigate the risk of crashes are also reviewed.	From 2003-2007 79 crashes at level crossings in Australia and New Zealand involved heavy vehicles, the majority of which involved articulated trucks. A number of actions were recommended, including: review of S*tandards Australia AS1742.7* and S10 of the *Guide to road design part 4: intersections and crossings*, with a particular focus on sight distance requirements. Development and promotion of a uniform restricted access vehicles permit. Promote the use of IAP to measure and monitor driver behaviours at level crossings. Amend where appropriate traffic management and road design guidelines and standards.
Geoff Anson consulting and InfraPlan (Aust) (2009)	Austroads report	Public	A report providing guidelines for use by key stakeholders to assess applications by heavy vehicle operators for access to local roads.	Outlines principles that should govern access to local roads, identifies the need for strategic thinking, the role of road network plans, and the importance of joint planning for transport and land use that involves important key stakeholders.
Geoff Anson consulting and InfraPlan (Aust) (2007)	Austroads report	Public	Outlines processes for identifying and planning rural and urban freight routes of importance.	A number of approaches have been utilised to identify freight routes for different purposes and contexts. Examples of approaches for high wide and commodity based networks that could be adopted across Australia are provided.
Houghton, McRobert, Patrick, &	Austroads	Public	A report to serve as a guide to deal with planning issues associated with development projects that will affect freight	Planning for freight in urban areas will involve transport management

Tsolakis (2003)	report		movements in urban areas.	professionals and urban planners. In the past urban freight has had little influence over transport and land use planning, however increases in the freight task and urban freight are driving a need for change in these areas.
Trevorrow & Wright (2011)	Report	Public	A literature review of existing studies and equipment relevant to the measurement of loads and stresses applied to pavement by heavy vehicles and resulting wear on the pavement surface.	Damage to pavements mainly occurs during braking, acceleration, and turning manoeuvres. Turning causes the most damage. In order to understand the impact of next generation freight vehicles on pavement surfaces it is necessary to quantify the horizontal tyre forces and pavement surface wear mechanisms. This needs to involve the application of full-scale loads under realistic tyre to pavement contact and temperatures, ruling out lab-based techniques.
Cunningham (2002)	Report	Public	A report outlining the truck-based geometric design standards for roads. Also includes traffic volumes and mix at which the adoption of such standards is economically viable.	Truck design performance characteristics were derived from the literature with a particular focus on the characteristics of the 6-axle semi trailer (typically the most common truck type on inter-regional freight routes). Based on the parameters identified a number of design standards were developed, including: horizontal curve standards based on limiting lateral acceleration, crest vertical curves based on stopping sight distance, horizontal curve radii and lateral clearances based on stopping sight distance, acceleration lane lengths, and vertical grades.
Gates & Noyce (2010)	Journal article	Public	An investigation of dilemma zone behaviour including brake response time, deceleration rate, and red light running at signalised intersections in Wisconsin. Data was obtained from 1,275 vehicles (motorcycles, cars, light trucks, single-unit truck, and tractor trailers).	Deceleration rates were highest for cars and light trucks (SUVs, etc.). Single unit trucks and tractor trailers demonstrated lowest deceleration rates. Deceleration rates were higher during off-peak times. Tractor trailers and single-unit trucks were 3.6 and 2.5 times respectively more likely to run a red light compared to passenger vehicles. Red light running was 1.3 times more likely during peak times compared with off-peak periods.
Chatti, Manik, Salama, Brake, Haider, El Mohtar, & Lee (2009)	Report	Public	An investigation of the impact of multi-axle trucks on pavement damage. 5 axle configurations and 5 truck configurations were studied.	Rutting damage due to different axle configurations is proportional to the number of axles; the damage per load carried is constant for individual axles. Fatigue damage due to different axle configurations increases with an increasing number of axles within an axle group for a given stress ratio.
Chatti, Manik, Salama, Brake, Haider, El Mohtar, & Lee (2009)	Report	Public	A study of the impact of multi-axle trucks on flexible and rigid pavement systems with a focus on flexible systems.	Multiple axle groups were found to have less damage in fatigue per load carried for both pavement types, however they were found to cause more damage in rutting of flexible pavements and roughness for rigid pavements. Testing of asphalt concrete indicated that multiple axles case less fatigue damage per load carried and rutting is proportional to the number of axles within the axle group. Mechanistic analysis demonstrated that multiple axles cause considerable stress reduction leading to lower fatigue damage. Full scale slab testing to examine joint/crack deterioration in plain concrete pavements was inconclusive.

Chatti, Manik, Salama, Brake, Haider, El Mohtar, & Lee (2009)	Report	Public	A study of the impact of multi-axle trucks on flexible and rigid pavement systems with a focus on rigid systems.	Multiple axle groups were found to have less damage in fatigue per load carried for both pavement types, however they were found to cause more damage in rutting of flexible pavements and roughness for rigid pavements. Mechanistic analysis demonstrated that multiple axles cause considerable stress reduction leading to lower fatigue damage. Multiple axles cause more faulting in rigid pavements.
Davis (2004)	Conference paper	Public	Addresses new developments and considerations for the design of downhill road sections with respect to the braking of heavy vehicles.	Considers issues associated with sustainable braking at various slopes and speeds. Engine braking and difference in various engine retarders are explored with regard to how these devices assist in the survivability of descents by heavy vehicles.
Di Cristoforo, Sweatman, & Kidd (2004)	Conference paper	Public	A presentation of findings from field trials evaluating the acceleration and deceleration performance of different heavy combination vehicles ranging in mass from 44 to 166 tonnes.	Tests carried out during the trials included acceleration from rest and deceleration from initial speed. These provide measures on the time to travel distance, time to reach speed, distance to reach speed, stopping distance, and average acceleration/deceleration for different heavy vehicles.
Prem, Ramsay, Fletcher, George, & Gleeson (1999)	Austroads report	Public	Reports on the findings of a performance-based method of assessing heavy vehicles for route access using computer modelling of the tracking ability of heavy vehicles.	Tracking ability is dependent on the cross-slope profile of the road, vehicle configuration, and travelling speed. Most heavy vehicles could travel comfortably on roads with a useable lane width of 3.5 metres with the exception of rigid-plus-three and A-triple configurations travelling at or above 90km/h.
Jurewicz & Comport (2008)	Austroads report	Public	An audit of rest areas along 12,700km of (mostly) AusLink freight routes. More detailed audits were carried out for 147 rest areas.	None of the audited routes fully met the spacing recommendations of the national guidelines; 60% of audited routes had significant deficiencies in the provision and frequency of rest opportunities. Major rest areas were under-provided in all jurisdictions. Three quarters of rest areas were not duplicated correctly on the opposite side of the road, with the exception of rest areas in Tasmania. Detailed audits revealed a relatively high compliance with recommended minimum parking requirements for different categories of rest areas. On average two thirds of recommended minimum site facilities were provided. Recommendations: the development of an empirical parking supply model for rest areas. Evaluation of the potential impacts of changes to driving hours regulations with regard to the provision of rest stops (rest area guidelines should be amended in line with these findings).
Borchardt (2002)	Journal article	Public	Analysis of safety benefits of truck restrictions of a 6 mile stretch of Houston freeway .	Traffic crashes were reduced by 68% without disruptions to freeway operations, travel time, or traffic patterns.
Bennett, Styles, Yeo, & Cox (2003)	Austroads report	Public	Examines the consequences of the introduction of PBS as a means of maintaining road safety and protecting road infrastructure.	Significant productivity benefits can be expected from the introduction of PBS in the Australian freight industry. Effective compliance strategies would provide benefits, including safety, to all stakeholders.
Lindsey (2009)	Conference	Public	A review of the potential benefits from separating cars and	Potential benefits depend on the relative volumes of cars and trucks, capacity

	paper		trucks into different lanes or roads.	indivisibilities and the safety hazard presented by each vehicle type. Differentiated tolls can support efficient allocations of cars and trucks between lanes. Lane access restrictions were observed to have limited effectiveness.
Fontaine, Dougald, & Bhamidpati (2009)	Report	Public	A report of the safety and mobility impacts of Virginia's truck lane restrictions.	Crash analysis of high-volume three lane segments revealed that crashes were higher than expected after the restriction was put in place and were not the products of growing congestion. Due to a high level of non-compliance with the restrictions no safety benefits were found for the restrictions on 2-lane interstates. Enforcement improved compliance, however this improvement was modest.
Fontaine (2008)	Journal article	Public	Reports the safety and operational findings of an evaluation of lane restrictions on four-lane interstate segments in mountainous areas lacking in truck climbing lanes.	Positive trends in crashes were observed with the number of fatal and injury crashes showing a significant decline. Compliance with restrictions in the evaluated areas was generally good, however a number of slow-moving vehicles (including cars) were still found to impede traffic in the left lane.
Jacques, Franklyn, Corben, & Candappa (2003)	Report	Public	An analysis of heavy vehicle run-off-road crashes in Victoria between 1998 and 2001 to determine the performance of safety barriers.	There is limited information available regarding the performance of barriers in impacts with heavy vehicles.
Milliken & de Pont (2004)	Transfund New Zealand research report	Public	The relationships between cross-sectional geometry and HV performance were used to estimate the effects of road geometry on HV crash risk.	The areas with potential for significant benefits in the reduction of HV crash risk include banking in curves, seal width and shoulder treatments, and cross-slope due to camber.
Mugarula & Mussa	Book	Public	A study to determine the operational and safety impacts of the restriction of trucks from using the median lane of a six-lane freeway corridor in Florida.	The difference between truck and passenger car speeds and travel times were insignificant on the unrestricted middle and shoulder lanes. Trucks were able to use the middle lane to pass 25% of the time during the truck peak-hour period with the assumption of a 10-s gap acceptance. Opening all lanes to trucks increased the number of lane-changing maneuvers by 11% in the daytime, which has the potential to increase the risk of crashing.
Andreassen (2003)	Conference paper	Public	An examination of HV crash data with regard to road design and roadside features.	There are areas of road design that do not cater for larger vehicles. The whole road system could be rebuilt to suit large vehicles. The use of large vehicles should be limited to specific road classes and routes. The design of HVs needs to be reconsidered to afford the driver greater vision of the area around their vehicle. Traffic regulations should be renewed and penalties for offences involving HVs should be greater than those for LVs.
McLean (2002)	Conference paper	Public	Suggests potential improvements to roads that are both cost effective and have the potential to reduce truck crash risk on two lane roads.	Roadside improvements including the retrofitting of shoulder seals was identified as a possible solution. Roads designed for low volume car and rigid truck traffic that are now part of the national truck freight route require particular attention.

Schneider, Zimmerman, Van Boxel, & Vavilikolanu (2009)	Journal article	Public	Uses statistical modeling methods to determine the effects of horizontal alignment on HV crashes.	A significant increase in truck crashes due to horizontal curvature and passenger vehicle volumes was observed.
Ko, Washburn, & McLeod (2009)	Journal article	Public	A study to determine the roadway, traffic, and control issues that should be the focus of efforts to better serve the needs of the trucking community.	On freeways, speed variance and pavement quality were important factors. On two-lane highways, important factors included percentages of time following or being followed, travel lane and shoulder width and pavement quality. On urban roads factors included ease of performing turning manoeuvres, speed variance, traffic density, and pavement quality. The behaviour of other drivers, pavement condition, level of congestion, and frequency and timing of road works were common factors independent of road type.
Reyner, Horne, & Flatley (2010)	Journal article	Public	Analysis of the effectiveness of motorway service areas in the UK at reducing the number of sleep-related crashes. Effectiveness was assessed by comparing crashes in the 16km following a service area to crashes in the 16km leading up to the service area. Crashes involving all vehicle types were included.	There was a non-significant reduction in crashes in the 16km following a rest area. There was a significant reduction in sleep-related crashes in the 16km following a rest area. The greatest reduction in sleep-related crashes that were potentially due to the provision of service areas was found for cars. Service areas seemed to have the least influence on sleep-related crashes between 2-6am, the time period when the greatest number of sleep-related crashes occur.

Table 4.2
Vehicle design implications for heavy vehicle road safety

Authors	Type	Availability	Research	Findings
Houser, Pierowicz, & Fuglewicz (2005)	FMCSA report	Public	A report to provide a better understanding of the function of on-board safety systems and provide insight into the safety and efficiency benefits of using such systems.	Describes the concept of operations and the voluntary requirements for the use of VSS for large trucks greater than 10,000 pounds GVWR.
Berg, Niewohner, Burkle, & Morschheuser (2001)	Journal article	Public	An investigation of 109 real life truck crashes and a crash test involving a Mercedes-Benz Actros.	Safety belts in heavy trucks have a potential to save drivers and passengers. Ejected truck occupants have the greatest probability of being killed in a crash.
Trevorrow & Eady (2010)	Austroads report	Public	A report to improve knowledge and understanding of heavy vehicle brake safety on long steep and very steep roads. Entailed a literature review, review of crash data, and a vehicle test.	Advanced braking systems offer increased safety in an emergency on steep roads due to the automatic application of the service brakes preventing roll-over or run-off-road crashes. While brake failure crashes accounted for less than one quarter of fatal truck crashes, brake failure crashes were found to be more serious. Fatal brake failure crashes were more likely on horizontal curves, however brake failure crashes on a combination of horizontal curve and vertical grade were more serious than those occurring on vertical grade alone. The main safety issue highlighted was the drivers' interaction with the auxiliary braking system. Inadequate owners manual information and a lack of real-time driver feedback regarding the performance (or lack thereof) of brakes were identified as important issues.
Lambert & Rechnitzer (2002)	MUARC report	Public	A review and report of the issue of rear and side underrun crashes.	Two major effects of underrun on the outcomes of crashes were identified: underrun can expose light vehicle occupants to the rigid structures of the truck before the safety features of the light vehicle come into effect; and damage to heavy vehicle components (e.g., steering, braking, etc.) can reduce the controllability of the truck during or after the crash. There is little evidence suggesting that improvements in truck underrun protection cannot be achieved. There is some evidence that enforcement of underrun requirements and standards is lacking. Performance of front barriers must have a significantly higher standard, at least twice that of rear underrun barriers. The requirements of barriers should extend to vehicles of 3.0 tonnes GVM. The desired characteristics of front and rear underrun barriers are also identified.
Hart (2010)	Conference paper	Public	Describes the development of the Australian brake balance code of practice to guide the intermixing of brake technologies on heavy vehicle combination vehicles.	A wide range of braking technologies can now be intermixed on combination vehicles, e.g., advanced electronic controls are being connected to basic vehicles. The recommended performance level set out by the code is that a combination vehicle be able to achieve an instantaneous deceleration level on a sealed 60km/h

				road of half the theoretical level without exhibiting gross wheel lock-up.
Johansson (2010)	Conference paper	Public	Paper outlining areas for improvements in heavy vehicle brake testing.	Heavy vehicle brake testing methods need to be improved to make testing more consistent and improve assessment of the technical condition of brakes. Key industry stakeholders (suppliers, garages, testing authorities, and companies) need to cooperate and adapt measures to improve brake testing. Legal rules and requirements should prioritise checks on systems that are important for road safety and where an associated cost-benefit can be demonstrated.
Miller & Cebon (2010)	Conference paper	Public	A study of the effectiveness of a sliding mode braking force observer to support a sliding mode controller for air-braked heavy vehicles. Involved computer simulations and vehicle testing.	The observer was found to operate robustly and provide reasonable estimates of surface friction. The estimator converged within 0.3 seconds in simulators and vehicle trials.
Parker & Sinnett (2010)	Conference paper	Public	Outlines the development and benefits of a pintle connection with the addition of a roll-coupling.	Research has shown the performance of truck/trailer configurations in terms of dynamic stability could be improved with the addition of a roll-coupling. Summarizes the results of torsion strength tests and stability tests of two prototype trailer hitches.
de Pont, Baas, Currie, & Hidvegi (2006)	Conference paper	Public	An investigation of the impact on performance of mixing heavy vehicle brake systems. Rigid truck and full trailer combination was modified so brakes would work in EBS or NZHVBC modes.	The best stopping distance performance was achieved by the NZHVBC brake system, however the EBS system allowed drivers to use full brake application with confidence under conditions where this was not possible with NZHVBC.
de Pont, Hutchinson, & Kalasih (2004)	Conference paper	Public	Outlines the implementation of the minimum roll stability requirement introduced in New Zealand in 2002.	Describes the phase-in time, certification requirements and procedures, documentation, and enforcement of the requirements. Outlines problem areas during implementation and how these were resolved. A preliminary assessment of the success of the stability requirement in reducing heavy vehicle roll over rate was also undertaken.
Li & McLean (2003)	Conference paper	Public	Presents findings on simulations of the behaviour of capillary and orifice controlled heavy vehicle air suspensions.	Current air suspension designs with capillary transmission lines are not road friendly and are also dangerous when their dynamic behaviour is taken into account.
Goldman, El-Gindy, & Kulakowski (2001)	Journal article	Public	A literature review regarding vehicle rollover with a focus on manoeuvre-induced rollovers.	Discusses issues of stability, rigid and liquid cargo, suspension, braking control, and warning devices.
Liu, Rakheja, & Ahmed (2001)	Journal article	Public	A study of the dynamic rollover limits of a straight truck under different evasive manoeuvres using roll plane models of heavy vehicles.	The dynamic rollover limit of a vehicle is manoeuvre dependent. Rollover limits at high steering frequencies are considerably larger than the static rollover threshold of the vehicle.
Gillespi, Karamihas, & Spurr (1998)	Conference paper	Public	An experimental study using computer modelling to examine the relative influence of various design factors in the directional behaviour of trucks during braking.	Asymmetry in the steering system of trucks with I-beam front axles was observed to cause deviation to the right in straight ahead and open-loop tests, even with symmetric loading & brake force. Lateral offset in load altered the directional behaviour; load bias to the left causes greater deviation to the right & vice versa.
Guzman & Navarrete (1998)	Conference paper	Public	A computer modelled analysis of heavy vehicle stability performance under overloaded conditions.	Overloading a rigid three axle vehicle has noticeable affects on brake time response, produces higher offtracking values and lowers the rollover threshold and

				manoeuvrability of the vehicle.
Simon & Botto (2001)	Conference paper	Public	An attempt to quantify the potential benefits achieved by the generalisation of 3 point seat belts to 100% of the European truck fleet. Analysis is based on 403 crashes involving 479 unbelted occupants.	The use of seat belts with 3 anchoring points in trucks that are also fitted with airbags would effectively prevent 37% of fatalities, 36% of serious injuries, and 22% of slightly injured truck occupants.
Morgan (2001)	NHTSA technical report	Public	Evaluates the effectiveness of retroreflective tape in enhancing the visibility of heavy trailers and reducing side and rear impacts under dark conditions.	The tape is quite effective, reducing side and rear impacts into trailers under dark conditions by 29%. In dark conditions retroreflective tape reduced side and rear impact crashes resulting in fatality by 44%. In dark-not lighted conditions the tape reduced side and rear impact crashes by 41%.
Charlton (2007)	Journal article	Public	Two groups of curve treatments were tested using a driving simulator to examine the roles of attentional, perceptual, and lane placement factors in driver behaviour at curves.	Advance warning signs alone were not as effective at reducing speed as when they were used in conjunction with chevron sight boards and/or repeater arrows. Of road marking treatments only rumble strips produced any reduction in speed. Herringbones road marking produced significant improvements in drivers' lane positioning for negotiating the curve. Treatments combining herringbones marking with chevron and repeater arrow signs improved lane positioning and produced a reliable reduction in speed. Treatments highlighting perceptual cues are the most effective means of moderating drivers' curve speeds.
Preece (2002)	Conference paper	Public	A review of seat belt use amongst drivers of heavy trucks, focussing on the attitudes towards, and prevalence of seat belt use.	The objections to seat belt use raised by interviewed truck drivers were incorrect or easily overcome. Many of these were similar to objections amongst the passenger vehicle fleet prior to the introduction of compulsory seat belt use. It has been estimated that seat belts have the potential to decrease fatalities amongst truck occupants by 40-50%; in New South Wales alone, the increased use of seat belts amongst truck occupants could save up to 10 lives per year.
Seyer & Jonas (2002)	Conference paper	Public	Discusses the possible integration of underrun protection and integrated lap/sash seat belts in heavy vehicles.	Any measures, such as underrun protection, that exploit the crashworthiness of modern passenger vehicles are worth consideration. Fully integrated lap/sash seat belts may be a possible strategy to encourage heavy vehicle occupants to wear seat belts.
Hart (2010)	Conference paper	Public	Estimates the forces that can occur in a heavy vehicle truck crash where one truck impacts the rear of another. Two 64.5 tonne B-double trucks are used.	Crash decelerations of up to 1lg can occur at relatively low collision speeds due to the high masses combined with stiff front and rear underrun protection. Discusses the implications with regard to the design rules relevant to seat belts.
Preece (2002)	Conference paper	Public	Examination of NSW crash data, interviews with truck drivers, and an observational survey of HV occupants' seat belt use.	Results provide overwhelming support for the safety benefits of seat belts for truck occupants. Also highlights the need to increase wearing rates.

Table 4.3
Vehicle safety technologies and on-board monitoring for heavy vehicles

Authors	Type	Availability	Research	Findings
Rakja, Fitch, Arafeh, Blanco, & Hanowski (2010)	Journal article	Public	A study to estimate the safety benefits of deploying forward collision warning systems across the national fleet of heavy vehicles. Involved the use of simulation models.	Estimated a potential 21% reduction in heavy vehicle rear end crashes, which equates to 4,800 fewer crashes on US highways per year.
Lee, Kourtellis, Lin, & Hsu (2010)	Journal article	Public	A study to evaluate the effectiveness of rear view video systems (RVS) for reducing reversing manoeuvre crashes of trucks.	Use of the RVS increased stop rates by 46.7% in straight line reversing manoeuvres, with increases of 4.4% for offset right and 17.8% for dock reversing manoeuvres. Drivers generally showed positive attitudes towards using an RVS with 90% agreeing that the RVS could reduce the rear blind spot for large trucks.
Davis, Karl, Cai, Bunker, Germanchev, Eady, & Blanksby (2010)	Journal article	Public	Reports on the accuracy, robustness, and tamper evidence of on-board mass measurement systems for heavy vehicles.	All systems tested showed accuracies within ±500 kg of gross combination mass, or ±2% of the attendant weighbridge reading. Analysis of dynamic data raised the possibility of using such dynamic information in tamper evidence, particularly in the identification of potential tampering or incorrect operating procedures.
Koniditsiotis (2000)	Report	Public	A report documenting the status of WIM technology in Australia.	There are 18 WIM type systems used or available in Australia. 3 broad applications of WIM technology were identified: infrastructure design and management, freight/trade planning and management, and detection and enforcement. Site selection and location characteristics are fundamental to the performance of WIM systems. WIM system users recognise the need to quantify the characteristics of WIM locations. There is a general dissatisfaction amongst WIM users with regard to the lack of uniformity in the procedures and frequency of WIM system calibrations. There is no standard Australian specification or method to evaluate WIM systems. WIM data should be made available in a form that is accessible to all users. A number of recommendations with regard to WIM hardware, usage, data, and application are provided.
Karl, Yu, & Luk (2007)	Austroads report	Public	A literature review undertaken to identify potential intelligent transport systems (ITS) technologies to reduce undesirable interaction between freight vehicles and other traffic using metropolitan networks.	The ITS technologies that appear to be most beneficial for road users include: improved timing and coordination of signal operations for freight vehicles, driver information systems, variable message signs, variable speed limit signs, heavy vehicle speed awareness systems, and access management and electronic tolling for privately funded roads.
Regan, Young, & Haworth (2003)	Report	Public	A literature review of ISA for both heavy and light vehicles.	Speed alerting and speed limiting ISAs have demonstrated benefits in the reduction of average mean speeds, speed variance, and speed violations. Improvements in interactions with other road users has also been observed. The greatest benefits of ISA is a reduction in fuel consumption followed by reductions in crashes.

				GPS based ISA systems appear to be the most flexible with the ability to vary the speeds of different vehicles using the same roads (e.g., cars and trucks).
Taranto, Young, & Logan (2011)	Report	Public	Attempts to estimate the potential reductions in serious casualties in Australia with the wide-spread adoption of DSRC crash-avoidance technologies.	The majority of serious casualties will be prevented by addressing adjacent, and opposite and same direction crashes. Estimates based on DSRC-based crash avoidance technologies providing warnings only (i.e., no physical interventions) of well-implemented DSRC technologies across the entire vehicle fleet indicate that total serious casualties could be reduced in the order of 25-35%.
Latto & Baas (2004)	Report	Public	An extensive literature review to identify new technologies affecting heavy vehicles.	Manufacturers of heavy vehicles are increasingly fitting enhanced safety features that afford drivers and other road users a greater degree of safety. Technologies fitted to vehicles were categorised under the following groups: braking, tyres and suspension, steering, vision, fuel efficiency, crash avoidance, vehicle monitoring, and crash mitigation. The introduction of new technologies and the associated benefits are strongly influenced by the rules governing heavy vehicle design and operation, and the public's perceptions of these technologies. The technologies are also linked with various compliance and enforcement strategies that may be pursued in the future. New technologies have the potential to improve vehicle safety and improve the efficiency of inspection and enforcement procedures, and a more efficient transport system.
Khemoudj, Imine, Djamai, & Jacob (2010)	Conference paper	Public	Proposes the use of smart systems to measure the impact of heavy vehicles on pavements and develop active control strategies to reduce dynamic effects.	A continuous on-board wheel load monitoring system could be a beneficial addition to anti-rollover and stability systems. One proposed method is to apply existing control techniques to on-board WIM technologies.
Coleman (2010)	Conference paper	Public	Assesses the relevance of Australian PBS in light of emerging active safety technologies.	Reviews various available technologies, how these affect on-road PBS performance, and outlines the tensions between delivering safety and productivity. Also evaluates alternative regulatory mechanisms. Proposes alternative tests to supplement PBS with the potential to improve safety and productivity.
Woodrooffe, Blower, Gordon, Green, Liu, & Sweatman (2009)	NHTSA report	Public	An examination of the performance of ESC and RSC systems for heavy truck tractor-semitrailers.	Crash scenarios from national crash databases (US) were selected and the probable effectiveness of ESC and RSC technologies were estimated. The potential safety benefits of these technologies were estimated based on simulations, field experience, and expert panel assessments.
Freund & Kreeb (2005)	Conference paper	Public	Discusses the safety benefits of technology for diagnostic and performance enhancement purposes with regard to tyres and brakes.	Results of research have the potential to improve commercial vehicle brake and tyre safety and reduce crashes related to failures in these components. This research could also improve productivity by reducing maintenance and life-cycle operational costs.
Vahidi, Stefanopoulou, Wang, & Tsao (2004)	Report	Public	Describes the experimental verification of compression braking control for heavy vehicles.	Simulations suggest the power-width-modulation actuation strategy will have the same speed regulation performance as the direct torque split strategy and

				significantly reduce the use of service brakes.
VanderWerf, Shladover, & Miller (2004)	Report	Public	A report that outlines the issues involved with time-staging the deployment of advanced vehicle control and safety systems (AVCSS) in light of a shift toward future automated highway systems.	In terms of the time-staging aspects of AVCSS deployment, heavy vehicle opportunities are likely to develop earliest, however the largest potential benefits are most likely with the application of these technologies to the much larger population of passenger vehicles.
Koleszar, Trencseni, & Palkovics (2004)	Conference paper	Public	Introduces the joint application of ESP and steer-by-wire systems in order to increase vehicle stability under different driving conditions.	Steer-by-wire (electrohydraulic steering) will provide an opportunity for other systems (e.g., ESP) to intervene into the vehicles directions control. Combining ESP with steering intervention will improve the functionality of ESP and its capability for stabilising the dynamic behaviour of vehicles.
Espie, Rajaonah, Auberlet, & Vienne (2004)	Conference paper	Public	An investigation of drivers' trust when using adaptive cruise control (ACC) using a driving simulator and questionnaires.	Reclaiming control with ACC is an important problem. The main issue for driver's trust in ACC is the interaction between the driver and the device.
Truett, Hwang, Chin, & Stevens (2002)	Conference paper	Public	Discusses the collection and analysis of truck rollover data. Also entails an evaluation of the reliability and accuracy of equipment used to take such measurements. Data was collected using vehicles in service with instrumentation on both the tractor and trailer.	Lateral acceleration and weight transfer can be related to road speed and location. GPS data is sufficient to determine a vehicles proximity to a curve. Used in conjunction this data can be used to determine highway locations where vehicles are routinely exposed to forces that overturn them. Demonstrates the potential of a device for providing drivers with a warning of a potential rollover in advance.
Rakheja, Romero, Lozano, Liu, & Ahmed (2002)	Journal article	Public	Describes the development of a three dimensional vehicle model to investigate the effectiveness of an open-loop roll instability control.	Rollover indicators and roll safety factors are investigated for their effectiveness in various cornering and evasive manoeuvres, road conditions, braking efforts, and driver reaction delays.
Charles (2001)	Article	Public	Describes the use of innovative ITS in freight transport in Australia, including cost efficiency and government benefits.	Outlines various ITS developments with regard to freight transport. Includes intelligent vehicles (with enhanced safety features such as collision avoidance and fatigue monitoring), e-commerce (measures to improve route guidance and vehicle loading, and provide electronic data exchange), and automated regulation (e.g., Safe-T-Cam and over-mass container systems).
Stevens, (2000)	Report	Public	Describes a test and evaluation of a truck rollover warning system.	The system included on-board instrumentation to continuously measure the stability of the trailer and determine the location and probable short-term path of the vehicle. Roadside beacons at selected curves broadcast characteristics of the curves to the vehicle. An on-board computer receives the data and estimates rollover risk based on roll stability, speed, and acceleration. If the estimated risk exceeds a specified threshold visible and audible warnings alert the driver in time to make corrective measures.
Sampson, Jeppesen, & Cebon (2000)	Conference paper	Public	Describes the development of an active roll control system for a tractor semi-trailer.	Simulations of the yaw-roll response indicate that the system will provide significant improvements in the rollover stability of heavy vehicles.
Allen (2010)	NHTSA technical report	Public	An evaluation of the effectiveness of ABS for heavy vehicles.	The best estimate of a reduction in all levels of police-reported crashes for air-braked tractor trailers for a tractor unit fitted with ABS is 3%. In fatal crashes there is a non-significant 2% reduction in crash involvement.

				Among the types of crashes ABS has the potential to influence: large reductions in jack-knives, off-road overturns, and at-fault crashes with other vehicles (except front-to-rear crashes) were observed. Increases in the number of involvements of hitting animals, pedestrians, or bicycles, and rear-ending lead vehicles (for fatal crashes only) were also observed.
Billing, Lam, & Vespa (1995)	Journal article	Public	An in-service evaluation of ABS fitted to all axles of b-train double tanker vehicles.	Tests demonstrated that ABS substantially improved the braking efficiency of combination vehicles under a wide variation of road surface and payload conditions. Also shows the benefit of using ABS on all axles.
Brown, Schwarz, Moeckli, & Marshall (2009)	NHTSA technical report	Public	Research to assess the effectiveness of tractor ESC on heavy trucks in terms of reducing the incidences of rollovers and jack-knives. The experiment used a driving simulator.	Benefits were found for both RSC and RSC+YSC systems to help drivers maintain control under differing conditions. The performance of RSC & YSC were dependent on the driver's speed. RSC demonstrated reductions in geometry based situations including tight curves and exit ramps. Drivers with RSC+YSC were 6 times more likely to avoid a jack-knife than drivers without any stability control system under similar driving conditions.
Mazzae & Garrott (2007)	NHTSA technical report	Public	Evaluation of commercially available rear object detection systems intended for use on medium straight trucks.	The performance of sensor-based systems was inadequate for the detection of people, particularly young children. Rearview video systems provide an effective means of seeing behind the vehicle. Rear cross-view mirrors are not an effective means of seeing behind a vehicle mostly due to poor/inconsistent image quality.
Sayer, Bogard, Funkhouser, Le Blanc, Bao, Blankespoor, Buonarosa, & Winkler (2010)	NHTSA technical report	Public	Findings from an operational field test of heavy trucks fitted with a warning system integrating FCW, LCM, and LDW warning functions were presented. The system was fitted to 10 heavy trucks for 10 months; vehicles were instrumented to measure driving behaviour and system performance. Surveys and debriefings were used to ascertain driver attitudes towards the system.	The integrated warning system offers benefits with regard to improved driver performance. The majority of drivers accepted the system and reported other subjective benefits of the system. The majority of drivers also indicated they would recommend that their companies consider purchasing vehicles with the integrated system installed. No negative behavioural adaptation effects were observed from the drivers' 10 month usage of the integrated system.
Koniditsiotis & Girgis (2010)	Conference paper	Public	Reports on the progress of the IAP which is used for monitoring heavy vehicles in Australia.	Outlines a number of benefits to transport operators. Describes the potential of future applications based on the IAP platform. Describes the benefits of IAP as a compliance tool.
Cai, Davis, & Karl (2009)	Conference paper	Public	Reports on the development and pilot testing of an OBM application for heavy vehicles.	Results of the pilot testing revealed non-linearity found in the range of ± 0.79% for trailer axle groups & ±1.3% for prime mover axle groups. Inaccuracy was found in the range of ±0.6% for trailer axle groups & ±1.15% for prime mover axle groups. Tamper testing was also undertaken. The capability of using dynamic data to determine the road friendliness of

				suspensions was also proven.
Blanksby, Talko, Patrick, Perovic, & Hore-Lacy (2008)	Conference paper	Public	Describes the suitability and cost-effectiveness of 14 technology options available for trailer monitoring as part of the IAP. A primary consideration was the inter-compatibility between technologies and IAP compliant prime movers and IAP compliant trailers.	Analysis of cost-effectiveness indicated that a stand-alone system allowing service providers to send trailer information to a centralised hub from which prime mover service providers collected the data and provided IAP reports on the whole vehicle was the most cost-effective option.
Bruzsa, Sack, & Shepherd (2006)	Conference paper	Public	Describes the trial of quad-axle semitrailer combinations that meet PBS requirements and are fitted with an OBM and GPS.	The results of this trial clearly illustrate the benefits of both IAP and PBS
D'Souza, Johnstone, & Koniditsiotis (2005)	Conference paper	Public	Uses the New South Wales mobile crane concessional benefit scheme (MCCBS) as a practical example of a successfully implemented IAP scheme.	The key features and lessons learned from the MCCBS demonstrate the practical applications for IAP and demonstrate how the benefits associated with IAP can be maximised in the future.
Koniditsiotis (2003)	Austroads report	Public	Outlines the findings on an investigation into the feasibility of the IAP, particularly identifying the applications to which IAP can be applied.	IAP can provide significant benefits to jurisdictions across all areas of activity including: improved road safety, reductions in infrastructure wear, reduction in environmental effects, management of public perceptions of heavy vehicle use, optimisation of road freight policy and operations tasks, and optimisation of on-road enforcement activities. The transport industry would also benefit from IAP in terms of improved productivity.
Hickman & Hanowski (2010)	FMCSA report	Public	Evaluation of a commercially available low-cost behaviour management system for drivers. Two different truck companies were involved in the evaluation.	Both companies significantly reduced driver involvement in safety-related events by 38% and 52%. The combination of on-board monitoring with behavioural coaching were responsible for the observed reductions in safety-related events.
Ball, Versluis, Hendrickson, Pittenger, Frank, Stewart, & Murray (2005)	FMCSA report	Public	Describes the factors that influence trucking companies' decisions to develop, purchase, and use on-board safety technologies.	The factors identified include: return on investment for the purchaser, the demonstrated effectiveness to improve safety, the reliability and maintainability of the technology, any liabilities that might arise due to data used or stored by the technology, market demand (for manufacturing), initial cost, investment necessary for the research and development of new technology, market image, driver acceptance, and in-cab technology interface and the manner this is integrated into the vehicle.
Misener, Nowakowski, Lu, Koo, Marguluci, Spring, et al. (2007)	FMCSA report	Public	Describes a suite of hardware and software to monitor driving behaviour and provide feedback on unsafe driving behaviours to the driver.	The system measures: speed, following distance, lane-keeping, seat belt use, and the use of turn signals.

Table 4.4
Heavy vehicle and other transport interaction

Authors	Type	Availability	Research	Findings
Delaney, Newstead, & Watson (2007)	MUARC report	Public	An examination of the effect of growth in heavy vehicle traffic on road trauma in the light passenger vehicle fleet. Predictions are modelled using exposure data from BITRE, the ABS, and NSW Police crash data.	The sensitivity of heavy vehicle related road trauma to crash risk is demonstrated. The importance of reducing heavy vehicle crash rates is highlighted with regard to reducing heavy vehicle related road trauma and to offset the projected growth of heavy vehicle travel.
Seyer & Jonas (2002)	Conference paper	Public	Discusses the possible integration of underrun protection and integrated lap/sash seat belts in heavy vehicles.	Any measures, such as underrun protection, that exploit the crashworthiness of modern passenger vehicles are worth consideration. Fully integrated lap/sash seat belts may be a possible strategy to encourage heavy vehicle occupants to wear seat belts.
Hanowski, Olson, Hickman, & Dingus (2006)	Conference paper	Public	Analysis of 246 heavy vehicle (HV) interactions with light vehicles (LV) collected in a naturalistic driving study via video cameras and other data collection devices fitted to light vehicles.	Excluding crashes where fault could not be determined LV drivers were at fault for 64% of identified incidents and HV drivers for 36%. When LV driver was at fault the most common incidents were: Late braking for stopped or stopping traffic, lane change without sufficient gap, and aborted lane change manoeuvres. When HV driver was at fault the most common incidents were: Lane change without sufficient gap, lateral deviation of through vehicle, and left turn (US) without clearance.
Hanowski, Hickman, Wierwille, & Keisler (2007)	Journal article	Public	Reports the joint findings of 2 naturalistic studies of HV-LV interaction. Video and other sources were used for data collection yielding 210 LV-HV critical incidents (crashes, near-crashes, and crash-relevant conflicts) for analysis.	78% of critical incidents were initiated by LV drivers and the remaining 22% by HV drivers. Aggressive driving on the part of the LV driver was determined to be the primary contributory factor for LV-initiated incidents. For HV-initiated incidents the primary contributory factor was determined to be poor driving techniques. Future efforts to address HV-LV interactions should include a focus on aggressive LV drivers, while HV drivers may benefit from improved training that includes defensive driving skills.
Evans & Frick (1993)	Journal article	Public	Examination of the risk of fatality due to differences in the mass of vehicles involved in a crash.	If a driver transfers to a car lighter by 1% that driver's risk of fatality in a 2-car crash is between 2.7% and 4.3% larger than that of the other involved driver. Two "laws" of mass ratio also apply across a wide spectrum of vehicles including trucks: Lghter vehicles present less risk to other road users The heavier the vehicle the less risk to its occupants.
Gao, Liu, Kong, & Guo (2004)	Conference paper	Public	Examines the influence of heavy vehicles on freeway safety in China.	The main causes of crashes are driving performance, loss for overloading, and significant speed variation between different vehicle types.

4.1 Gaps in research

Limited research internationally has indicated that lane and speed restrictions for heavy vehicles can improve road safety on some roads. Future research should seek to evaluate the effectiveness of such strategies on Australian freight routes. For example, the South Australian Government has recently initiated a strategy involving lane and speed restrictions and increased signage for trucks descending the South Eastern Freeway between Crafers and Adelaide. This presents an opportunity to assess the effectiveness of such strategies under Australian conditions.

Anecdotally there is evidence that the drive for improved safety in the design of heavy vehicles and trailers is driven more by the consumer than by imposed regulations however, no research addressing this issue was identified. The introduction of design rules and regulations regarding the aggressivity and crashworthiness[1] of heavy vehicles has the potential to improve the safety of all vehicles bought and sold in Australia. As such research into the mechanisms that influence the adoption of safer vehicles may shed light on this issue. Such research would also prove useful for informing either the need to introduce regulation or the form such regulations should take. It would also be useful to monitor developments with heavy vehicle safety features as implemented in other markets such as Europe.

There is a body of literature describing the development of digital short range communications (DSRC) and the potential safety implications such technologies have. However, to date no real evaluations of the effectiveness or safety benefits of DSRC technologies have been conducted. Research is required to determine the effectiveness of these technologies and the manner in which they can best be utilised.

Safety technologies will continue to be developed and evolve to deliver improved performance and functionality. Additionally, due to the costs associated with purchasing and implementing new technologies, evaluations of the safety and productivity benefits of new and existing technologies is warranted. Such research will enable operators within the trucking industry to make informed decisions with regard to the best technology solutions for their operations.

There are some indications that the Intelligent Access Program (IAP) provides a cost-effective option for monitoring heavy vehicles' use of the road network. At the same time, IAP may also benefit heavy vehicle road safety and productivity however no formal published evaluations could be found. Industry perceptions regarding the validity and effectiveness of the IAP are less favourable (B. McKinley, personal communication, May 12, 2011). Given this, there may be opportunities with the creation of the new national regulator to fine tune the IAP program to take into account the experiences of key stakeholders from within the trucking industry.

[1] Aggressivity refers to a vehicle's ability to protect other road users in the event of a crash, while crashworthiness refers to the protection a vehicle provides its occupants in a crash.

5 Human and social factors

This section is devoted to the human and social factors that influence heavy vehicle safety. It addresses health, sleep and fatigue issues (including fatigue management), substance use, and driver training.

Table 5.1 addresses general aspects of human factors such as driver training, attitudes, and general behavioural issues. Table 5.2 addresses aspects of health and fitness to drive (with the exception of fatigue), and Tables Table 5.3 and Table 5.4 address issues of sleep, fatigue, and fatigue management. Table 5.5 addresses issues related to the use of licit and illicit substances.

Human factors and heavy vehicle road safety

With regard to general human factors (attitudes and behaviour) and fitness to drive some general conclusions to be drawn from the studies outlined in Table 5.1 and Table 5.2 include:

- Training drivers in techniques to drive more economically by learning to flow with the traffic has no negative impact on travel time and may have added safety benefits.
- It appears that training or systems that provide drivers with feedback or information regarding the effects of their driving can improve their safety.
- The use of seat belts among HV drivers remains much lower than that of passenger vehicle users.
- Studies of heavy vehicle drivers skills conducted in Canada have indicated that drivers with poor literacy or numeracy skills are more likely to be involved in safety related incidents than drivers whose skills meet the required standard.
- Studies of the effects of common prescription medications on driving performance are lacking, representing an area that would benefit from further research.
- Truck driving has been associated with a number of health outcomes, particularly obesity, cardiovascular disease, diabetes, and sleep apnoea.
- Depression, anxiety, and substance use, among HV drivers is comparable with the general Australian population however, they face more barriers to seeking treatment. These factors are also associated with an increased risk of crashing. Improving access to treatment will benefit drivers and their safety on the road.

The relationships between driving performance, crashes, fatigue and sleep-related factors in the heavy vehicle industry

There is a large pool of research investigating the influence of fatigue and sleep-related factors on driving performance and crashes in both commercial and non-commercial drivers. This research covers a diverse range of topics including the prevalence of sleepy driving and sleep related crashes, the risk of crash associated with driving while sleepy, and the severity of sleep-related crashes. Factors that may lead to fatigue/sleepiness are also often considered such as time of day, circadian rhythm, sleep disorders, and prior sleep. There is also a wealth of research on countermeasures, fatigue detection technologies, and performance impairments (both general human performance and driving performance) that occur due to fatigue. Table 5.3 summarises some of this research.

One important difficulty in fatigue research is the variation in the definition of fatigue in different studies. Perspectives on the definition of fatigue change both within and between disciplines and therefore there is not one single accepted definition of fatigue among researchers. Although some

researchers have tried to incorporate definitions into a single concept, these efforts have not been accepted. In order to gain a thorough understanding of the effects of fatigue multi-disciplinary definitions need to be refined and there must be some agreement between researchers. In the mean time, individuals attempting to make sense of the literature must take into account differing definitions and the effect this may have on results. Therefore, in order to gain a more complete picture of the influence of fatigue in the heavy vehicle industry, research considered in this section has included studies investigating fatigue, sleepiness, and drowsiness of varied definitions and determined by a range of methodologies.

From the research listed in Table 5.3, there are a number of trends which can be highlighted, some of these include:

- Truck drivers may be at greater risk of fatigue and sleepiness related crashes due to the nature of their work hours (e.g., night shifts and long working hours), their work conditions (e.g., stress, monotony), and their lifestyle (e.g., risk of medical conditions including sleep disorders due to sedentary lifestyle, for further information see Table 5.4).
- Fatigue has been associated with an increased risk of crashing in a large number of studies. The extent of this risk depends on the severity of fatigue as well as the method of data collection and analysis in the various research studies. Inexperienced or young truck drivers may be at greater risk of being involved in a fatigue-related crash.
- A large proportion of fatal truck crashes are likely due to fatigue; drivers of articulated trucks are likely to have a greater risk of being involved in a fatigue related crash. Fatigue is a concern with regard to drivers of articulated trucks as, on average, these vehicles travel much further distances than all other vehicle types (ABS, 2008). Due to the greater risk of sleep-related crashes, the nature of sleep related crashes (e.g., often no avoidance manoeuvre is involved) and the size of trucks involved (meaning there is a greater force transfer during crashes), the severity of fatigue related truck crashes is of concern and demonstrates the importance of this issue.
- Fatigue leads to performance impairment, both in general human performance, and driving ability. Specifically, fatigue can lead to impairment in attention and reaction times, perception of bodily movements and position, tracking tasks, and more complex tasks compared to simple tasks. Vehicle control variables including lane and steering control are also likely to be impaired due to fatigue. The effect of fatigue on performance impairment is not small and has been previously compared to alcohol related impairment.
- The prevalence of chronic partial sleep restriction is more common than total sleep deprivation. This is of importance as recovery from chronic partial sleep deprivation is not as rapid as that of total sleep deprivation and impairment may last over several days even with recovery sleep. Due to the working conditions of truck drivers, this population is likely to be more exposed to chronic partial sleep deprivation in everyday life.
- There are a large number of factors that are likely to lead to fatigue. Well known factors include the circadian rhythm and time of day, work arrangements (including hours of service and work-related pressures), opportunities for rest breaks, prior sleep debt and so on. However, there are many other less recognised factors which are likely to contribute to fatigue (for an extensive but not exhaustive list, see Milia, Smolensky, Costa, Howarth, Ohayon & Philip, 2011).
- The use of stimulants (particularly amphetamines) to combat the effects of fatigue by some drivers in the trucking industry is of concern. Truck drivers who use

amphetamines to combat fatigue may be at greater risk of a fatigue-related crash. Amphetamines fail to overcome the performance decrements associated with fatigue and other performance impairments are associated with the use of amphetamines.

- Fatigue detection technologies are improving over time, however those which are currently available still require further validation before they are implemented in trucking companies.
- Evaluations of rest areas and prescribed driving hours suggest that some aspects of the regulated driving hours are incompatible with the provision of rest stop facilities. Furthermore, in many instances the provision of rest stops is inconsistent with prescribed standards. Stakeholders within the trucking industry argue that the driving hour limitations may restrict drivers from reaching a suitable destination to take prescribed rest break within the allotted time. However, a survey of long-haul drivers (Sadural et al, 2001) suggests the main reasons for drivers exceeding permitted driving hours regulations were mainly associated with reward factors.
- There is evidence of discrepancies between driver and industry perceptions with regard to fatigue management: managers within the industry think fatigue is well managed, however driver reports are less favourable.

The relationship between sleep apnoea and sleep-related performance impairment and crashes

Sleep apnoea is defined by the American Psychiatric Association as a breathing-related sleep disorder which causes sleep disruption leading to excessive sleepiness (DSM-IV TR: American Psychiatric Association, 2000). Due to these effects the relationship between sleep apnoea and crashes has been extensively studied. As the results of this body of research are relatively consistent a sample of the most relevant studies are summarised in Table 5.4. The evidence related to sleep apnoea and crash risk or driver impairment indicates that sleep apnoea is likely to lead to impairment in driving performance as well as increased risk of crash. The reason for this relationship may be due to a number of factors including poor quality sleep and excessive sleepiness.

The finding that sleep apnoea leads to increased crash risk is of particular concern in the trucking industry as sleep apnoea is prevalent within the trucking population and truck drivers are more likely to develop sleep apnoea due to lifestyle factors. Sleep apnoea may also interact with other sleep-related crash risk factors found more commonly in truck drivers leading to even greater crash risk.

The research findings presented in Table 5.4 also demonstrate that treatments for sleep apnoea can be effective in reducing the increased risk of crash associated with the disorder. Continuous Positive Airway Pressure (CPAP) is one particular therapy that has been focused on in previous research and shows promising results, however not all sleep apnoea patients respond to CPAP therapy and therefore other interventions should also be considered.

Substance use

Studies regarding heavy vehicle drivers' use of legal and illegal substances are somewhat contradictory. Crash statistics (see Table 1.1) indicate that heavy vehicle drivers involved in crashes are less likely to have used illicit substances compared to the drivers of the passenger vehicles that are involved in crashes. However, these statistics also indicate that in crashes where the heavy vehicle driver is at fault the incidence of illicit substance use appears to be much higher. To further cloud the issue, research regarding the substance use of HV drivers tends to suggest that the prevalence of substance use amongst this population is at least comparable to the broader Australian population. Given the general prevalence of substance use in Australia it would be expected that

some substance users will appear in the workforce in general and, therefore, within the HV industry however, this problem is not isolated to the HV industry. Taken as a whole this evidence at least suggests the presence of a sub-population of substance using drivers who have an increased risk of crashing compared to drivers who do not use substances.

Further evidence regarding substance use by HV drivers suggests the following:

- The substances most commonly used by HV drivers are stimulants (e.g., amphetamines, stay-awake-pills, pseudoephedrine, etc.) with around 25-35% of HV drivers reporting that they generally use these substances to combat fatigue.
- Substance use may differ among different sub-populations of HV drivers. For example, the prevalence of stimulant use appears to be higher among long-haul drivers, drivers who work through the night, and drivers whose payment is contingent on the amount of work they do, while younger drivers are generally more likely to use illicit substances.
- There is little published literature providing details of current substance use management practices. Although there is mention of zero tolerance policies towards substance use, there is a lack of published information on testing regimes (mandatory or otherwise).

Table 5.1
Human factors in heavy vehicle road safety

Author	Type	Availability	Research	Findings
Symmons, Rose, & Van Doorn (2009)	Report	Public	An evaluation of the benefits observed during a trial of ecodriving with heavy vehicle drivers involving follow-ups at 6 and 12 weeks and control group comparisons.	Improvements were observed in the following areas: fuel use, number of braking applications, and number of gear changes. No sacrifice in overall speed or driving time were observed. Effects remained at the 12 week follow up and in some cases progressive improvements were observed.
Symmons & Rose (2009)	Conference paper	Public	Outlines the results of an ecodrive training course for heavy vehicle drivers.	Drivers reduced fuel consumption by 27%, the number of gear changes by 29% and number of brake applications by 41%. No increases in travel time were observed. Members of a control group comparison used more fuel, changed gears more, and applied their brakes more often. Safety benefits were inconclusive.
Watanabe, Matsunaga, Shidoji, Matsuki, & Goshi (2005)	Journal article	Public	Describes a driver support system designed to warn drivers when the headway between the truck and vehicle it is following is shorter than the recommended stopping distance.	Assessment of the ASSIST system successfully increased following distance by warning the driver to increase the gap.
Hickman (2005)	Conference paper	Public	An evaluation of the impact of a self-management for safety process for short haul truck drivers. Pre-driving intentions were self-reported prior to leaving the terminal. Post-driving measures of actual driving behaviour was recorded using an on-board computer monitoring device measuring speeding and extreme braking.	During the intervention the pre-driving group reduced their mean percentage of time speeding by 30% and mean braking percentage by 64%. The post-driving group reduced mean speeding percentage by 20% and their mean extreme braking percentage by 50%.
Winkler, Sullivan, Bogard, & Hagan (2004)	Conference paper	Public	Examines the influence of speed, load condition and individual driving style on the lateral performance of truck drivers. Uses data recorded from six tractor-semitrailer combinations that were heavily instrumented and tracked for one year.	Interesting asymmetries in lateral performance are presented. Other factors identified as having a significant influence on lateral performance include weather, lighting, and turn direction.
Kuncyte, Laberge-Nadeau, Crainic, & Read (2003)	Journal article	Public	This paper outlines the approaches to truck driver training for the transportation of dangerous goods that have been adopted in the U.S., Canada, The Netherlands, and Sweden.	In Canada and the U.S. the responsibility to ensure drivers are adequately trained lies with the employer; driver assessment is also an employer responsibility. Many employers use commercial training firms, however there is no accreditation scheme for these programs. In Europe training and testing must receive national accreditation, however the details of this accreditation are not clearly spelled out. Sweden places an emphasis on the accreditation of those providing training. The Netherlands places emphasis on the examinations used to assess the results of training. The same goal in four different countries has resulted in four different schemes.

Lang (2007)	FMCSA technical brief	Public	A synthesis of knowledge regarding heavy vehicle driver training strategies intended to identify driver training tools and techniques with the greatest potential for improving the safety of commercial motor vehicles.	Recommendations: Industry-wide acceptance of and adherence to recognised standards for minimum requirements for drivers and driver trainers. Completion of training for 1st seat drivers. Replace printed classroom materials and practices with multimedia instructional tools. Expansion of the use of skid pads in driver training. Integration of video and experienced driver testimonials to provide a realistic introduction/orientation to fitness to drive.
Hickman, Hanowski, & Bocanegra (2010)	FMCSA report	Public	A study of the prevalence of mobile phone distractions and the risk associated with driving performance tasks utilising naturalistic data from buses and trucks.	Talking/listening on a mobile phone while driving was generally not found to significantly impact the odds of involvement in a safety-critical event. Mobile phone sub-tasks such as texting, dialling, and reaching for the phone were found to significantly increase the odds of involvement in a safety-critical event.
Cook, Hoggins, & Olson (2008)	Journal article	Public	An observational study of heavy commercial vehicle drivers' seat belt use.	Observed seat belt usage rate was 64%, approximately 20% lower than national (US) rates for passenger vehicle drivers.
Poulter, Chapman, Bibby, Clarke, & Crundall (2008)	Journal article	Public	Uses the Theory of Planned Behaviour to understand factors that influence truck drivers' behaviour and compliance with regulations.	Law abiding behaviour was related more to attitudes, subjective norms, and intentions. Perceived behavioural control had the largest direct effect on compliance with UK truck regulations. Future interventions that seek to improve on-road behaviour or compliance with regulations require different approaches.
Howarth, Alton, Arnopolskaya, Barr, & Di Domenico (2007)	FMCSA report	Public	A literature review of the non-regulatory factors that influence the safety of commercial motor vehicle drivers.	Employee turnover is an issue that may lead to poor safety performance associated with inexperienced drivers. Drivers' decisions to stay with an organisation were largely based on the compensation they received; carriers that paid better wages were more likely to retain drivers. A driver's driving history is an important factor with future crash involvement being predicted by past driver behaviours, particularly prior involvement in a crash. Increased pay was also associated with a reduction in crashes, although the mechanisms for this interaction were the subject of speculation. Safety management best practices were also important, particularly commitment to safety by management, employee involvement, prioritising safety through all aspects of operations, and making safety management a continuous process.
Brock, McFann, Inderbitzen, &	Book	Public	Evaluates the effectiveness of commercial motor vehicle driver training curricula and delivery methods.	There are no national standards on content however there is a general consensus across the industry regarding the core content of training curricula.

Bergoffen (2007)				The preferred method of training involves a combination of classroom lectures and supervised driving, however these approaches do not incorporate many of the advances in adult learning and instructional techniques. There is a tendency to use older experienced drivers as instructors, however there is no evidence that someone who is a job expert is necessarily a good teacher. There is a lack of standards for measuring the effectiveness of driver training programs beyond simply how many graduates pass their CDL test.
Hagge & Romanowicz (1996)	Journal article	Public	An early evaluation of the traffic-safety impact of the California Department of Motor Vehicles' Commercial Driver License (CDL) program introduced in 1989.	The CDL program did not have a significant effect on traffic safety.
Kim & Yamashita (2007)	Journal article	Public	A survey of 791 commercial vehicle drivers regarding their attitudes towards seat belt use.	67% reported always using a seat belt when driving a commercial vehicle. The major reasons reported for not wearing a seat belt included stopping frequently, inconvenience, and not being safety conscious.
Burgewood Ltd (2005)	NTC discussion document	Public	Examines the links between seat comfort and seat belt use among HV drivers.	There are some commonly held assumptions about seat and belt configurations that, when tested, do not hold up. Other misconceptions, including the perception that wearing seat belts is dangerous, also contribute to low rates of compliance with seat belt laws. There are a range of options to address better seat belt design that may help remove the perceived barriers to seat belt use.
Haworth, Bowland, & Foddy (1999)	Report	Public	A study of truck driver seat belt wearing based on interviews with 184 truck drivers.	72% of drivers reported never using a seat belt in the truck they were driving. 16% indicated that the seat belt had been removed or one was never fitted. 4% of drivers reported wearing a seat belt all the time. Drivers of rigid trucks were more likely to report using a seat belt compared to articulated truck drivers. Reasons for not wearing: 35% indicated that seat belts were uncomfortable, 27% believed they had no safety value or were dangerous. Reasons for wearing included safety or enforcement consequences.
Krueger, Bergoffen, Knipling, Hickman, Short, Murray, Inderbitzen, & Reagle (2005)	Conference paper	Public	Interviews and surveys were used to obtain HV drivers and fleet safety managers opinions regarding HV drivers' use of seat belts.	The findings confirm many of the issues already reported in other studies throughout the literature base. An ergonomics assessment of the most commonly found seat belts in class 8 trucks was also undertaken.

Bergoffen, Knipling, Tidwell, Short, Krueger, Inderbitzen, Reagle, & Murray (2005)	Book	Public	A synthesis of research focussing on the factors that influence commercial vehicle drivers' decisions to wear seat belts and potential areas for improving seat belt use amongst these drivers. Involved interviews with managers, drivers, and an ergonomic assessment of old and new seat belt technologies.	The majority of drivers indicated that they wore seat belts either all or most of the time. Their reasons for wearing included safety, because it was the law, it was habit, and they had seen or been involved in a crash. The major complaints of drivers regarding seat belts were that the belt: rubs or vibrates against the neck or shoulder, locks, is uncomfortable, is too tight, and has a limited range of motion. Drivers indicated seat belts would be easier to use if they were not too tight, did not interfere with driving, were easy to put on or off, and easy to position. Ergonomic assessment indicated that the majority of seat belts were practical and functional; newer belts have features that make them more user friendly and older belts are not as effective with large- or small-statured individuals. It was also found that drivers were not fully aware of the features that made seat belts comfortable and easy to use.. New technologies for seat belt comfort and design are also discussed.
MacLeod (2002)	CTHRC report	Public	An investigation to identify learning needs in the professional driver and dispatcher work force.	A significant number of professional drivers have poor literacy skills, particularly for workers aged 40-50 with low levels of formal education. Outlines the essential skills required for the trucking industry.
MacLeod & Kline (2004)	CTHRC report	Public	Investigates the relationship between the reading text, document use, and numeracy skills of 231 petroleum professional drivers and the likelihood of having a safety incident.	There is a correlation between essential skills proficiency and the likelihood of having a safety incident. Drivers who did not meet or exceed the upper end of the reading text standard or the document use standard were 1.58 and 1.69 times respectively more likely to have been involved in a safety incident than drivers who met these standards. Older drivers had poorer skills in each of the domains. Drivers with more years of formal education had better skills in each of the domains.

Table 5.2
Health and fitness to drive/fitness for duty

Author	Type	Availability	Research	Findings
Dionne, Desjardins, Laberge-Nadeau, & Maag (1995)	Journal article	Public	A study estimating the effect of different medical conditions on truck drivers' distribution of crashes. The study controlled for age, medical conditions, and exposure factors.	Truck drivers with diabetes licensed to drive straight trucks had more accidents than drivers of good health. None of the other medical conditions examined in the study had a significant effect on crash distributions. Many of the risk exposure variables were also significant.
McKnight, Shinar, & Hilburn (1991)	Journal article	Public	A comparison of the performance of 40 monocular and 40 binocular tractor-trailer drivers on measures of visual acuity and driving performance.	On the visual measures monocular drivers were deficient in a number of areas. Of the driving measures monocular drivers did not perform as well as binocular drivers only in the aspect of sign-reading distance, a task that was correlated with binocular depth perception. Monocular drivers are not significantly worse than binocular drivers in terms of the safety of most day-to-day driving tasks.
Duke, Guest, & Boggess (2010)	Journal article	Public	A review of age related and other safety factors contributing to the crashes of heavy vehicle drivers.	Drivers younger than 27 years of age were found to have higher rates of crash/fatality involvement. Increased rates of crash/fatality involvement were also observed for drivers aged 63 years or more. Other factors contributing to HV crashes included long hours and sleepiness and fatigue, vehicle configuration (particularly multiple trailers), employer safety culture, urbanisation, and road classification.
Hilton, Staddon, Sheridan, & Whiteford (2009)	Journal article	Public	A study of the impact of mental health symptoms on the performance of heavy goods vehicle (HGV) drivers. 1324 HGV drivers were surveyed.	Depression, anxiety, and stress were found to have little effect on absenteeism or self-rated driving performance. Severe (1.5% of drivers) and very sever (1.8% of drivers) depression was associated with an increased risk of being involved in a crash or near miss in the past 28 days by 4.5 and 5 times respectively . Given the number of HGVs and the prevalence of depression it is estimated that there are 10,950 HGV drivers with an increased statistical risk of a crash or near miss.
National Transport Commisssion (2010)	Report for comment	Public	Outlines the key changes and impact of changes to the assessment of fitness to drive, particularly a shift in emphasis towards functionality rather than simply diagnosis.	Driver licence authorities: increasing the emphasis on functionality rather than diagnosis and improving the clarity of medical criteria will simplify the application of the standards and improve administrative efficiency. Health professionals: A focus on driving ability rather than disease diagnosis may require more professional judgement and input to the driver licensing authorities, but will improve the useability of the standards. Drivers: A focus on function rather than diagnosis will facilitate a more relevant assessment of drivers.
Meuleners & Lee (2008)	Book chapter	Public	Documents the health profile of heavy vehicle drivers and identifies relevant work place issues based on data collected from 302 drivers in Western Australia.	The majority of drivers were either overweight or obese and engaged in low levels of physical activity, if any. Around 50% were smokers, 58% suffered from tiredness while driving and 56% slept

				less than 6 hours per day. 51% did not eat the recommended daily amounts of fruits and vegetables. 53% reported chronic illness and 19% experienced a work-related injury requiring medical treatment in the past 12 months. Companies rarely provided medical check-ups for their drivers.
Robinson & Burnett (2005)	Journal article	Public	Uses US mortality data to calculate proportional mortality ratios for heart disease and lung cancer for short and long-haul drivers.	The highest significant excess proportionate mortality for lung cancer, ischemic heart disease, and acute myocardial infarction was found for drivers who were under 55 years of age at death.
Moreno, Louzada, Teixeira, Borges, & Lorenzi-Filho (20060	Journal article	Public	A study to verify the association between sleep patterns and factors associated with obesity in 4,878 Brazilian truck drivers.	28% of truck drivers in the study were obese (BMI ≥30 kg/m^2). 25% of drivers were on medications and 7% were diabetic. Drivers with the greater BMI also exhibited short sleep length. Factors associated with obesity included sleep duration of less than 8 hours per day, being over 40 years old, glucose levels over 200, cholesterol levels greater than 240, snoring, and hypertension. Short sleep duration and being over 40 years old is associated with obesity and a number of other health care problems.
Laberge-Nadeau, Dionne, Maag, Desjardins, Vanasse, & Ekoe (1994)	Conference paper	Public	Study of the association between commercial vehicle drivers' medical conditions and crash severity.	Truck drivers with binocular vision problems and bus drivers with hypertension were involved in more severe crashes than healthy drivers. Variables describing crash circumstances were also significant.
Mackie & Moore (2009)	Conference paper	Public	Reports on the health issues identified for New Zealand log truck drivers, and also provides the preliminary findings of an evaluation of a driver fitness program "Fit for the road".	Twice as many log truck drivers were obese compared with New Zealand males of similar age. "Fit for the road" has had a positive impact on the lives of participants. Work is needed to address wider systemic issues within the industry that may affect drivers' health and well-being.
Gillett (2008)	Report	Public	A study to identify the prevalence of mental health disorders in NSW transport workers.	Truck drivers were found to have a slightly lower prevalence of moderate or high psychological distress than the Australian workforce in general. 13% of truck drivers were found to have some degree of depression; 91% of these were not in treatment. HGV drivers were also found to have substantial barriers to treatment. Being divorced increased the odds of a driver being depressed or experiencing symptoms of anxiety. 27% of NSW truck drivers were identified as having the potential for hazardous or harmful alcohol use. 24% were considered mild and 1% were in the highest risk category. Alcohol use was significantly related to anxiety levels. Drivers aged 34-45 years old had an increased risk of hazardous or harmful alcohol

				use. Being a casual HGV driver increased the odds of crashing when compared to full or part-time drivers. Mild to severe alcohol use also increased the risk of crashing. Depression symptoms had the largest effect on risk of crashing or having a near miss. On average NSW truck drivers work longer hours during the week compared to other Australian full-time employees. The number of hours a truck driver worked was directly related to increased stress levels. 12% of drivers indicated the use of a drug either daily or weekly. Drivers' marijuana use was similar to that of the general population, however drivers' use of all other drug types was found to be at least double that of population norms. Drivers aged 25-34 years old or 65 years and older reported the highest levels of drug use in the past month. Other risk factors for drug use were: being single, being an owner/operator long haul driver, and working more than 80 or less than 40 hours per week.
Husting (2005)	Conference paper	Public	A summary of recent findings and research regarding truck driver health and wellness.	Factors related to work organisation have the potential to impact driver well-being, increase drivers' lack of fitness, increase fatigue and inattention, reduce quality of life and longevity, and increase anxieties about, and exposure to violence. Appropriate well-designed interventions and evaluations are needed to clarify and rectify these issues.
Orris, Buchanan, Smiley, Davis, Dinges, & Bergoffen (2005)	Book	Public	A literature review of health and fatigue issues for commercial motor vehicle drivers.	Lung cancer may be caused by exposure to diesel exhaust with longer exposure increasing the likelihood that a cancer will develop. There is some evidence that cardiovascular disease is caused in part by truck driving. The risk of cardiovascular disease increases with the length of time spent driving trucks. Disruption of circadian rhythms may have a negative impact on the general health of workers and may influence gastrointestinal disorders.

Table 5.3
Sleep issues, sleepiness, fatigue, and fatigue management

Author	Type	Availability	Research	Findings
Barr, Popkin, & Howarth (2009)	Report	Public	A review of recent developments in mathematical modelling and vehicle-based operator alertness monitoring technologies.	Reviews and discusses current activities with regard to the development of unobtrusive, in-vehicle, and real-time drowsy driver detection and fatigue monitoring/alerting systems.
Swann (2002)	Conference paper	Public	Reviews the issues of drugs, alcohol, and fatigue in heavy vehicle safety.	Truck drivers use stimulants for occupational reasons. Drivers with sleep disordered breathing have an increased risk of an accident. 16% of heavy vehicle drivers have both sleep disordered breathing and symptoms of excessive daytime sleepiness, both of which can be successfully treated.
Mahon & Cross (2000)	Conference paper	Public	Outlines the findings of a pilot study of the FMP trialled in Queensland as an alternative to existing prescriptive approaches. The FMP requires heavy vehicle operators to have rostering and scheduling practices that consider fatigue-relevant issues in order to achieve accreditation.	Government prescriptive approaches to fatigue management lack clarity and can be confusing. A number of benefits were associated with the FMP: Increased awareness of fatigue issues and management/prevention strategies. Improved lifestyle Reductions in the frequency of fatigue symptoms and the use of negative coping strategies. Numerous business benefits including reductions in accidents and injuries, improved staff morale, and improved management and productivity.
Anund, Kecklund, Vadeby, Hajlmdahl, & Akerstedt (2008)	Journal article	Public	Reports the findings of an experiment utilising a moving base simulator to determine the effects of milled rumble strips on driver fatigue. Rumble strips were simulated for both the edge line and centreline; 4 different designs of rumble strips were used.	Results showed an increase in sleepiness indicators prior to hitting the rumble strip, and an alerting effect after hitting the strip. The observed alertness effect was short lived and signs of sleepiness returned in 5 minutes following the hitting of the rumble strip.
Hanowski, Hickman, Olson, & Bocanegra (2009)	Journal article	Public	Evaluates the impact of an additional driving hour (increase from 10 to 11 hours) on the critical incident (crash or near miss) involvement of truck drivers. Data was collected as part of a naturalistic truck driving study.	Analyses found an elevated risk of critical incident involvement in the first hour of driving, but no consistent significant differences between hours 2 through 11. Analysis of time of day of critical incident involvement identified a strong positive correlation to national traffic density data. This study found that there was no increased risk of experiencing a critical incident from truck drivers driving in the 11th hour compared to the 10th or any other hour.
National Transport Commission (2006)	NTC technical report	Public	Presents a summary of fatigue management information that has been used in the development of advanced fatigue management (AFM) option policy.	Presents detailed accounts of fatigue management programs and research studies relevant to AFM.
Economic Associates Pty Ltd (2003)	NTC regulatory impact statement	Public	Examines the impacts of regulations and code of practice to manage fatigue in heavy vehicle drivers.	A weakness of the regulatory scheme is a focus on drivers' hours of work rather than the causes of fatigue. Regulated working hours may be inadequate for the following reasons: Prescribed minimum breaks may be inadequate;

				Requirements for short breaks are too rigid; Regulations are inflexible; TFMS provides scheduling flexibility for, but places few fatigue management obligations on, employers; Regulations do not recognise the need for the active management of fatigue; The focus of enforcement remains on drivers rather than those who influence or make scheduling decisions. The paper also outlines compliance options, standard hours, BFM, AFM, chain of responsibility, code of practice, work diaries and record keeping, and enforcement aspects of the proposed changes to the regulations.
Williamson, Friswell, & Feyer (2004)	NTC research report	Public	Compares the impact of day and night shift rosters on the fatigue and performance of heavy vehicle drivers.	Night shifts made drivers feel more tired than day shifts, but did not produce significantly poorer performance, indicating that night shift drivers are able to adequately manage their fatigue.
Williamson, Sadural, Feyer, & Friswell (2001)	Information paper	Public	An Australian survey of 1007 long distance road transport drivers	Drivers reported fatigue less often than they had in the previous survey. Most drivers reported that they experienced fatigue in the first 10 hours of driving. Drivers experienced fatigue most often during the early morning and to a lesser extent in the early afternoon. Factors that drivers identified as increasing fatigue included long driving hours and problems associated with loading and unloading (particularly delays). Strategies drivers reported as most effective for managing fatigue include: sleep, rest, drinks containing caffeine, and “stay-awake” drugs. Fewer drivers in the current survey reported using “stay-awake” drugs. Owner-drivers do longer trips but appear to have greater flexibility over trip scheduling. Fatigue-related incidents are common occurrences for long distance drivers. Drivers most commonly broke working hours regulations due to work organisational and reward factors. Drivers paid in terms of the amount of work they did reported more fatigue than drivers paid at an hourly rate. The survey demonstrated little change in the working conditions of long distance truck drivers between 1991 and 2001 although awareness of fatigue appears to have improved and the occurrence of fatigue has reduced.
Feyer, Williamson, Friswell, & Sadural (2001)	Information paper	Public	A survey of 200 Australian transport companies regarding knowledge, awareness, and management of fatigue.	The majority of companies reported that awareness of fatigue has increased over the past 5 years, however this increased awareness did not guarantee better management. Half of the companies surveyed reported that fatigue was well managed and 20% reported that it was badly managed. It appears that drivers knowledge and awareness of fatigue issues is much better than the companies that employ them. The majority of companies reported having considerable control over work schedules with strict estimated times of arrival being uncommon. Companies reported less intervention and active management of fatigue for non-employee drivers.

				The survey suggests that there is considerable scope for improving the understanding and management of fatigue in the industry.
AMR Interactive (2007)	NTC research report	Public	A survey of 613 heavy vehicle drivers regarding fatigue and its effects on drivers. Results of this survey are compared to earlier surveys of the same issues undertaken in 1991 and 1998.	75% of drivers view fatigue as a significant problem in the road freight industry and many drivers believe fatigue is not well managed within the industry. While many drivers report experiencing fatigue related issues when driving, very few drivers consider fatigue to be more than a minor problem for them. Long working hours was considered one of the most important contributors to fatigue. Other factors included irregular or inadequate sleep and other aspects of work such as having to stick to regulations, and heavy traffic. 40% of drivers reported occasionally driving contrary to regulations. Driving without taking breaks was influenced by driving schedules and conditions, and the drivers' motivations to make money. Common reasons for not stopping for a break included scheduling and practical (e.g., nowhere to stop the truck) limitations.
AMR Interactive	NTC research report	Public	A survey of 314 heavy vehicle freight companies regarding attitudes towards and knowledge of fatigue.	A number of changes were observed with regard to attitudes, knowledge, and practices observed in 1998: Perceptions that fatigue is well managed in the industry have increased. Improvements in the implementation of formal fatigue and medical policies to include subcontractors, etc. Perceptions of increased awareness of driver fatigue within the industry were lower than those observed in 1998. Improvements in knowledge regarding causes of fatigue and effective fatigue management strategies. Improvements in the determination of trip times.
Warner & Talko (2010)	Journal article	Public	An overview of a draft performance-based specification for heavy vehicle driver fatigue monitoring systems to enable the use of electronic work diaries (EWDs).	Authorities are yet to approve EWDs due to the ambiguous provisions within the HVDF legislation. Enabling the use of EWDs will present stakeholders with numerous opportunities in other areas such as the generation of management reports or the introduction of non-roadside enforcement practices.
Brewer, Camilleri, & Zapanta (2010)	Conference paper	Public	Describes a rest stop provision strategy implemented in conjunction with new heavy vehicle fatigue management regulations.	Outlines the criteria for the selection of locations and the facilities provided at rest areas.
Cleaver, Simpson, de Roos, Hendry, & Peden (2009)	Conference paper	Public	Outlines the use of blue reflectors to indicate the location of informal rest areas for truck drivers.	The reflectors also provide a reminder to truck drivers of their obligations to manage fatigue. The blue reflectors are used in a number of Australian states and are recognised by the heavy vehicle industry.
Baas, Charlton, &	Conference paper	Public	An evaluation of compliance with driving hours regulations and fatigue.	A sizeable number of drivers exceeded allowable driving hours. High levels of fatigue and sleepiness were also observed.

Bastin (2000)				
Johns, 2000	Journal article	Public	A sleep physiologist studied sleep-related factors and drowsy driving. He suggested factors which may determine the likelihood of someone falling asleep at any given time.	It was found that the likelihood of falling asleep at any given moment in time can involve a number of factors including an individual's likelihood of falling asleep on average (e.g., trait sleepiness), length of time awake, time of day, activity the individual is involved in, and posture.
Goel, Rao, Durmer & Dinges, 2009	Journal article	Public	A thorough review was conducted on the neurocognitive consequences of sleep deprivation.	Found a number of cognitive functions are impaired by sleep loss. These deficits occurred in psychomotor performance (vigilance and speed), response inhibition, working memory, cognitive speed, executive functions and higher cognitive functions such as decision making, focused attention and lateral thinking. Individuals who are sleep deprived are not always aware of the severity of their impairment. Some individuals may be genetically predisposed to the cognitive impairments associated with sleep loss. Biological clock generates the circadian rhythm which effects sleepiness levels. Extended wakefulness also leads to sleepiness and the increased likelihood of falling asleep. Time-on-task can lead to increased cognitive impairment, this fatigue effect is more prominent after sleep deprivation. The cognitive impairments due to sleep loss are often highly variable both within individuals and between individuals.
Jung, Ronda, Czeisler & Wright, 2010.	Journal article	Public	Investigated the effect of sleep deprivation on sustained auditory and visual attention. Performance was measured every two hours during 40 hours of sleep deprivation.	Sleep deprivation lead to impairment in both visual and auditory attention however visual vigilance was more impaired and more variable compared to auditory vigilance. Impairments included longer response times, increased lapses (failure to respond within 10ms), inappropriate responses. Time-on-task also increased with increasing impairment.
Johns, 2010	Journal article	Public	A review was conducted on the concepts of sleep and wakefulness including what sources of variance may lead to an individual's likelihood of falling asleep (sleep propensity).	The three sources of variance related to an individual's sleep propensity included average sleep propensity of that individual, the capacity for the person's posture, activity and situation to facilitate the onset of sleep, and the way the individual responds to those particular circumstances.
Moller, Kayumov, Bulmash, Nhan & Shapiro, 2006	Journal article	Public	A study was conducted to investigate the circadian fluctuation in alertness and performance on a driving simulator in healthy individuals.	Objective measures of performance (e.g., reaction time) showed circadian variation, however subjective measures did not, suggesting a lack of awareness of some sleep-related deficits. Micro sleeps were relatively common in the late afternoon and an increase in micro sleeps was strongly correlated with an increase in crashes.
Franzen, Siegle & Buysse, 2008	Journal article	Public	After a night of normal sleep or total sleep deprivation, a group of healthy participants completed objective and subjective measures of sleepiness as well as emotional regulation and vigilance tasks.	Sleep deprivation lead to increased subjective and objective sleepiness. After sleep deprivation the participants were more reactive to emotional stimuli, had longer reaction times and more lapses (reaction times greater than 500ms).
Roads and Traffic Authority,	Roads and Traffic Authority Report	Public	Some criteria for determining if fatigue was involved in a crash, post-crash, were reported on. Crash statistics in	In order for a crash to be considered fatigue related, the report states that at least one fatigued driver must have been involved in the crash. To meet these criteria the police must have suspected the driver was asleep, drowsy or fatigued, or the manoeuvre must

NSW Centre for Road Safety, 2008			NSW were also included in the report.	have suggested fatigue. For example, a vehicle travelling on a straight road drifting into head-on traffic when not overtaking or travelling there on purpose for some other reason. Or, If the vehicle travelled off the side of a straight road or left the outside of a curve when excessive speed was not involved and no other reason could be identified for the manoeuvre. Fatigue was involved in 16% of all fatal crashes and 9% of all injury crashes in NSW in 2008. Regardless of fatigue, 0.8% of all crashes were fatal, however 2% of all fatigue related crashes were fatal in NSW in 2008.
Queensland Transport, 2008	Queensland Transport Report	Public	QLD crash statistics for the financial year of 2007-2008 were reported on.	17.5% of fatal crashes were fatigue related.
Van Dongen, Maislin, Mullington & Dinges, 2003	Journal article	Public	Using an experimental design, the effects of chronic sleep restriction and total sleep restriction on neuro-behavioural functioning was investigated.	The researchers argued that chronic sleep restriction is particularly relevant to every day life compared to total sleep restriction. Impairments in psychomotor vigilance, working memory and cognitive throughput were found after chronically restricting sleep to 4 and 6 hours per night. Participants did not adapt to chronic partial sleep deprivation, after 14 days, cognitive deficits were comparable to those after 1 to 2 days of total sleep deprivation. Subjective sleepiness ratings were greater after total sleep deprivation and initially after chronic partial sleep deprivation, however, these ratings showed adaption to the chronic partial sleep deprivation. That is, after 14 days of chronic partial sleep deprivation, cognitive performance was at it's worst, however participants reported only feeling slightly sleepy. After chronic sleep restriction, participants spent less time in stages 1, 2, and REM sleep. Those who naturally sleep longer may be more affected by 14 days of sleep deprivation.
Horne & Reyner, 1995	Journal article	Public	Two surveys were conducted in southwest England and the midlands using police databases and interviews to determine the time of day and prevalence of sleep related crashes. Criteria for assessing the involvement of sleep in a crash were included.	Criteria for identifying a sleep related crash included a BAC below the legal limit, no signs of braking, speeding, following too close, or mechanical defect. The weather must have allowed for clear visibility and the police officers must have suspected sleepiness as a prime cause at the scene. Finally, the vehicle was required to have run off the road or run into the back of another vehicle, and for several seconds before leaving the road or hitting the vehicle, the driver would have been able to clearly see the hazard. In 1987 to 1992 inclusive, 16% of all crashes in which police were called in southwest England were found to be sleep related. Three peaks in sleep related crashes were found, 2-3am, 6-7am, and 4-5pm. 23% of all crashes on motorways in the midlands during August 1991 and 1992, and April 1994 were sleep related. There was a peak in sleep-related crashes between 12am-3am and during the mid-afternoon. Sleep related crashes can occur even after a short period of driving due to the influence of the circadian rhythm.
Gander, Marshall,	Journal article	Public	An investigation of the prevalence of fatigue in truck crashes was conducted. The researchers demonstrated	There are a number of different issues with identifying fatigue in a crash. That is, drivers may not be fully aware of their fatigue or it's effects, there may be little evidence of fatigue

James & Le Quesne, 2006			the difference between two different methods of determining the presence of fatigue in the crashes.	symptoms at the crash scene, and often crash investigators have insufficient knowledge of fatigue in order to reliably determine it's involvement. Crash reports suggested only 5.1% of truck crashes in New Zealand during 2001 and 2002 involved fatigue. However, when other factors were considered, such as physiological risk factors and the driver's opinion of fatigue involvement, 17.6% of crashes were classified as fatigue related. Somewhere between 29-59% of fatigue related crashes may not be classified as fatigue related on crash reports.
Connor, Whitlock, Norton & Jackson, 2001	Journal article	Public	A review of international epidemiological studies investigating the involvement of sleepiness in car crashes was conducted using an assortment of cross-sectional studies and one case-control study.	The better quality studies reviewed indicated there was likely to be a positive relationship between fatigue (due to either sleep disorders, shift work, sleep deprivation, or excessive daytime sleepiness) and crash risk. Evidence for a causal role however is weak from the epidemiological evidence.
Cummings, Koepsell, Moffat & Rivara, 2001	Journal article	Public	Factors related to driver drowsiness and countermeasures were investigated in relation to crash risk using a case-control design in rural Washington State during 1997 and 1998.	Drivers who felt they were falling asleep at the wheel, those who slept equal to or less than nine hours (compared to 12 hours) in the previous 48 hours, and drivers who drove longer distances were at greater risk of crash. Those who used rest stops, drank coffee within the preceding two hours, or used their radios were at less risk of crash. By stopping driving when drivers are fighting sleep, using highway rest stops, drinking coffee, using the radio, getting at least nine hours sleep in the 48 hours prior to a trip, and avoiding long distances or sharing driving may reduce risk of crash.
Connor et al., 2002	Journal article	Public	Using a case-control design, the contribution of sleepiness to serious injury crashes was investigated in New Zealand during 1998 to 1999. Factors leading to increased risk of crash were identified.	Greater acute sleepiness was related to greater risk of crash. Drivers who felt they were sleepy, reported less than five hours sleep (compared to those reporting more than five hours) in the preceding 24 hours, and those driving between 2-5am were at greater risk of crash. Chronic sleepiness was not associated with an increase in crash risk.
Fell & Black, 1997.	Journal article	Public	A telephone survey investigating the relationship between fatigue and crashes in metropolitan areas was conducted in the region of Sydney in 1995. Information from both crashes and near-crashes were included in the survey.	27% of drivers involved in a fatigue-related crash or near-crash reported they had not felt tired at the start of their trip, despite this they all acknowledged that the crash was due to fatigue. Risk factors for a fatigue related incident may be due to tiredness due to sleep loss, late night driving, and shift-working. City fatigue related driving incidents tended to occur on work trips or commuting to and from work, as well as social trips.
Quarck, Ventre, Etard & Denise, 2006	Journal article	Public	A within-subjects experimental design was used to determine the effects of 26-29 hours of sleep deprivation on the vestibular-ocular-reflex, a measure of vestibular functioning.	A change in the vestibular-ocular reflex was found after sleep deprivation. The researchers suggested that the related impairment in vestibular functioning may lead sleep deprived individuals to misperceive their own body's movement in space.
Swann, Yelland, Redman & Rajaratnam, 2006	Journal article	Public	The researchers used event related potentials to determine the effects of partial sleep deprivation on automatic and selective attention.	The findings of the study suggested that sleep partial sleep deprivation can lead to impairment in the ability to automatically detect change and that the brain recruits more resources to sustain selective attention while sleep deprived.

Drummond, Paulus & Tapert, 2006	Journal article	Public	The researchers investigated the effects of two nights of consecutive sleep deprivation on participants ability to inhibit responses. Recovery from this impairment was also investigated with two nights of recovery sleep.	The study found both one and two nights of total sleep deprivation lead to an impairment in ability to inhibit inappropriate responses. By the second night of sleep deprivation participants produced increased errors of omission Both of these impairments returned to normal after one night of recovery sleep
Belenky et al., 2003	Journal article	Public	The effects of either three, five, seven, or nine hours of partial sleep deprivation over seven days on psychomotor performance was evaluated. The recovery of performance was also measures over three days of recovery sleep (eight hours in bed over night each night).	The researchers argued that studies of chronic partial sleep deprivation are more relevant to every day life, compared to total sleep deprivation, because this is more likely to occur outside the laboratory. During sleep deprivation, speed and lapses remained at baseline levels for the nine hour group. For the seven hour group there was an initial reduction in psychomotor speed which then stabilised at a slowed rate. The effect was similar for the five hour sleep restriction group however this group also experienced greater numbers of psychomotor lapses. The three hour group had increasingly slower reaction times and greater numbers of lapses over the seven days of sleep restriction. During recovery sleep, there was no evidence of recovery found in the five or seven hour sleep restriction group. Impairment in speed and lapses in the three hour group recovered after one night of recovery sleep however they did not recover to baseline levels, rather they stabilised at a level of impairment similar to the five and seven hour group. Recovery from chronic partial sleep restriction is not as rapid as that of total sleep deprivation.
Lamond & Dawson, 1999	Journal article	Public	The researchers compared the effects of sleep deprivation to that of alcohol intoxication using a number of tasks including simple sensory comparison, unpredictable tracking, vigilance (accuracy and latency), and grammatical reasoning (accuracy and latency).	28 hours of sustained wakefulness lead to impairment on all tasks other than the accuracy of grammatical reasoning and the simple sensory task. The more complex tasks in the study were more sensitive to the effects of fatigue compared to the relatively simpler tasks. After 20 hours of sustained wakefulness, performance impairment was equivalent to a BAC of 0.10%.
Maruff, Falleti, Collie, Darby & McStephen, 2005	Journal article	Public	The researchers extended the work conducted by other researchers on the relative effects of sleep deprivation and alcohol on performance. They suggested their design to be more accurate as they accounted for changes in the variability of data.	The researchers argued that previous studies overestimated the effect of fatigue on performance because they did not take into account changes in performance variability. Performance impairment after 24 hours of sustained wakefulness corresponded with the impairments found at a BAC of 0.05. Increased reaction times were found with sustained wakefulness, while performance on psychomotor tasks also increased in variability,
Lim & Dinges, 2010	Journal article	Public	A meta-analysis of seventy previous studies was conducted in order to investigate the impact of sleep deprivation on a number of cognitive variables including simple attention, complex attention, working memory, processing speed, short-term memory, and reasoning.	Complex tasks were found to be less sensitive to sleep deprivation compared to simpler tasks. Sleep deprivation impaired performance in most cognitive domains. Simple attention and vigilance was most affected by sleep deprivation. Complex attention and working memory tasks were only moderately affected by sleep deprivation. Accuracy of reasoning and crystallised intelligence were not influenced by sleep deprivation.

				Sleep deprivation differentially effects the various cognitive domains but does not bias people to respond faster or more accurately.
Urrila, Stenuit, Huhdankoski, Kerkhofs & Porkka-Heiskanen, 2007	Journal article	Public	The researchers investigated the effects of age on 40 hours of total sleep deprivation related performance impairment in women.	Sleep deprivation lead to impairment in psychomotor vigilance. Age did not influence this impairment.
Philip et al., 2004	Journal article	Public	The researchers compared the performance of a younger (20-25 years) and older age group (52-63 years) on a reaction time task after a night of sleep deprivation and after a night of sleep.	After a night of sleep the older participants produced slower reaction times compared to the younger participants. After a night of sleep deprivation the younger participants produced slower reaction times but the older participants' reaction times remained unaffected.
Otmani, Roge & Muzet	Journal article	Public	The researchers investigated the effects of age and time of day on sleepiness ratings in professional drivers. The study used a driving simulator task during the afternoon and evening and subjective and objective sleepiness was measured during the tasks.	The younger drivers experienced greater decreases in alertness during the driving tasks compared to middle-aged drivers. The levels of sleepiness reported were greater in the younger group both during and after the driving tasks. There was no difference found in objective sleepiness measures during the driving task between the groups. Both subjective and objective sleepiness measures showed the drivers were less alert and more sleepy during the evening compared to the afternoon simulated driving session. With less traffic during the simulated tasks there was greater objective sleepiness.
Mortazavi, Eskandarian & Sayed, 2009	Journal article	Public	The relationship between drowsiness and performance on a truck simulator in commercial vehicle drivers was investigated. The simulated scenario involved a monotonous section of highway and was completed by the drivers during the morning (commencing 8:30-9:30am) and at night (between 1:30am-5:00am).	Greater drowsiness lead to impairment in lane keeping and steering control Crashes seemed to be preceded by two phases of changes in steering wheel use behaviour. Firstly, lane keeping and steering control variables were affected. The second phase involved 'dosing off' in which the steering angle was constant and there was no input from the driver. Run off road crashes were associated with this latter phase. There are individual differences which suggest drowsiness detection systems based on changes in steering wheel behaviour may fail to issue warnings for some drivers or in some situations, whereas in other cases they may give false alarms.
Charlton & Baas, 2001	Journal article	Public	The relationship between fatigue, work/rest cycles and performance (psychomotor and driving simulator) was conducted in 606 truck drivers. The tests were conducted at truck stops, depots and ferry terminals in New Zealand.	Truck drivers worked five days per week on average with most shifts averaging about 11 hours. The truck drivers reported an average of approximately 7 hours sleep in the previous 24 hours. Fatigue was considered a greater problem for other drivers than themselves and only 63% of the truck drivers stated that fatigue was 'always' dangerous for drivers. The researchers suggested that older drivers may be more susceptible to fatigue related impairment Age and length of prior rest/sleep predicted failure rates on the driving simulator. The researchers did not directly study this but suggested professional drivers may be less susceptible to fatigue impairment due to their greater driving experience.

				The researchers suggested at the time of the study, the current regulations for service hours were not effective in managing fatigue or driver compliance.
Akerstedt, Peters, Anund & Kecklund, 2005	Journal article	Public	The relationship between driving performance and sleepiness after a night shit was conducted using a driving simulator in shift workers. Driving performance was measured after a night shift and after a normal night of sleep.	Lane position variability and number of incidents increased while the time to first accident decreased after night shift compared to after a night of sleep. The duration of eye closure was longer and subjective sleepiness also increased after night shift compared to after a normal night of sleep.
Boyle, Tippin, Paul & Rizzo, 2008	Journal article	Public	The performance impairment on a driving simulator during micro-sleeps in a group of drivers with sleep apnoea was compared to performance outside of micro-sleeps.	Driving performance during micro-sleep episodes was found to be reduced compared to periods of wakefulness. This reduced performance was related to both the duration and occurrence of micro-sleeps.
Schmidt, Schrauf, Simon, Fritzsche, Buchner & Kincses, 2009	Journal article	Public	A simulated monotonous daytime driving scenario of 428km was used to assess drivers' subjective and objective state of vigilance and how this related to the monotonous driving task.	There was a continuous reduction in objective vigilance found over the 428kms, however, subjective vigilance followed this trend until the final section of the drive. At this stage, the subjective and objective measures of vigilance did not equate, with subjective ratings of vigilance improving while objective measures continued to deteriorate. The researchers suggested the knowledge that a monotonous trip is soon to be completed may make drivers feel their vigilance levels have improved while their actual state of vigilance continues to become increasingly impaired with continued driving.
Davey, Richards & Freeman, 2007	Journal article	Public	A study was conducted in order to determine the patterns of use and reasons for illicit drug use among long-distance truck drivers.	There were a number of different reasons for drug use in the truck drivers, one of the main reasons was in order to combat fatigue. The most common illicit drug used by the drivers was amphetamines.
Oron-Gilad & Ronen, 2007	Journal article	Public	The researchers sort to determine the influence of road characteristics (such as curved, straight and mixed roads) on fatigue-related performance in a driving simulator.	Driving is a fatigue inducing task, that is, drivers can experience fatigue early in a drive even when they are not tired or sleep deprived. Fatigue symptoms show large individual differences Driving performance impairments due to fatigue were found to relate to the road environment, that is, not the same impairments were found in curved and straight roads.
Fournier, Montreuil & Brun, 2007	Journal article	Public	Observations of both experienced and inexperienced truck drivers while working were used to determine the differences of these individuals in fatigue management and implicate possible areas for improvement in truck driver training.	Experienced drivers may have developed skills to manage their work demands as a whole, not simply via basic time management but also by being aware of changes in their own psychological and physical state and by continuously re-evaluating their working situation, and therefore may be better equipped to manage their own fatigue compared to inexperienced drivers. By monitoring and managing their own state, as well as actively avoiding situations which can lead to stress, may lead to slower fatigue development. Continuously re-evaluating situations may also be able to aid in this way, as well as allowing for better time management to allow for rest breaks and avoid feeling pressure to drive while fatigued to make up lost time. Inexperienced drivers may be so preoccupied with deadlines that they may not be in a psychological state which allows them to re-evaluate the situation compared to experienced drivers. Fatigue-related driver training may benefit from including, not only basic time management principles, but also relevant work-related planning in the context of issues

				that often occur in the daily life of truck drivers on the job.
Woods & Grandin, 2008	Journal article	Public	Using accident reports of commercial livestock truck crashes between 1994 and 2007 in the US and Canada, the involvement of fatigue was investigated.	The researchers suggested that a large proportion of livestock truck crashes are due to fatigue because 59% of the crashes occurred between 12:00am and 9:00am and the majority were single vehicle crashes (80%). In addition, 85% of the crashes were considered due to an error on behalf of the truck driver.
Heaton, Browning & Anderson, 2008	Journal article	Public	Using a logistic regression analysis, the researchers attempted to determine which variables can predict falling asleep while driving in truck drivers. Demographic variables, sleep-related variables, and the Epworth Sleepiness Scale was used.	Four variables were found to predict falling asleep at the wheel within the previous 30 days, these included, an Epworth Sleepiness Scale score over 10, greater than six hours night-time driving duration, working more than 13 hours in a 24-hour period, and using medications related to sleep and wakefulness. An ESS score greater than 10 lead drivers to be at three times greater the risk of falling asleep at the wheel. Those truck drivers who reported greater than six hours night-time driving were four times as likely to fall asleep at the wheel compared to those reporting fewer hours. Working more than 13 hours lead to 2.5 times the risk of falling asleep while driving compared to those who worked less than 13 hours in a 24-hour period. Those truck drivers using medications were nearly five times more likely to fall asleep while driving. Years of experience was not related to an increase in risk of falling asleep, nor was driving solo compared to driving with a partner at least 50% of the time.
Duke, Guest & Boggess, 2010	Journal article	Public	A literature review was conducted to determine the relationship between age and crashes/safety in professional heavy vehicle drivers.	The researchers focused on age-related safety however, they also reported that long hours and related sleepiness and fatigue contributed to heavy vehicle crashes. The researchers noted that there is inconsistent evidence on the age-related effects of fatigue on crash risk, however larger studies suggest that younger drivers may be at greater risk, suggesting that younger drivers may be more suited to short haul driving.
Milia, Smolensky, Costa, Howarth, Ohayon & Philip, 2011	Journal article	Public	The researchers conducted a review of both endogenous and exogenous variables that can potentially lead to fatigue and/or the recognition and response to it on behalf of individuals.	The researchers considered a number of variables in their review which they commented on. Endogenous variables with the potential to influence fatigue included: genetic factors, gender, age, race, nutrition, BMI, endurance (both mental and physical), circadian strength, chronotype, phase and desynchrony, personality, sleep requirement and debt, and health status (physical and psychological). Exogenous variables with the potential to influence fatigue included: Working arrangements, time and method of commuting, physical and cognitive state at commencement of shift, the start time and duration of the shift, workload, motivation, time since last sleep, quality and duration of sleep, napping, recovery time between shifts, meal timing and content, work conditions, medication and drug use, job control, monotony, and so on.
Department for Transport, Energy and Infrastructure (DTEI), 2010	DTEI report	Public	An investigation of the prevalence of heavy vehicle crashes in South Australia and the relationship between these crashes and a number of variables, including fatigue, were presented in the report.	In SA during 2005-2009, 17% of fatal heavy vehicle crashes involved fatigue. More articulated compared to non-articulated trucks were involved in fatigue related crashes. Inconsistent definitions of fatigue makes the involvement of fatigue in crashes difficult to determine.

				The potential role of fatigue can also be difficult to determine post-crash.
Klauer, Dingus & Neale, 2009	Symposium proceedings	Public	The differential effects of fatigue and driving performance for single and team long-haul truck drivers were compared in a naturalistic study.	Solo drivers were four times more at risk of drowsiness related incidents compared to team drivers. The researchers suggested this was because team drivers were more likely to change driving duties prior to excessive fatigue. In comparison, solo drivers were more likely to continue driving while fatigued.
Moore-Ede, Heitmann, Guttkuhn, Trutschel, Aguirre & Croke, 2004	Journal article	Public	The application of the Circadian Alertness Simulator or CAS (a mathematical model designed to predict fatigue) was evaluated by the researchers within the field of trucking.	The researchers argued that the CAS was effective in predicting fatigue in the trucking application. By providing managers with the CAS, these managers could then make informed decisions on fatigue risk, the differences in decisions made based on the CAS lead to significantly reduced crash rate and severity of heavy truck crashes.
Dijk & Larkin, 2004	Journal article	Public	The authors commented on the theoretical basis behind current mathematical models of fatigue prediction (including the CAS) and suggested areas for future research.	The researchers suggested that the theoretical basis behind mathematical models of fatigue prediction need to be re-evaluated, with most models using relatively simplistic algorithms with minimal variables. Furthermore, the assumptions underlying the models in terms of the relationship between these variables, other sleep-related variables and performance requires further validation. The researchers noted that the ability for the CAS to use individual data in predictions is commendable.
Anund & Kircher, 2009	VTI report	Public	The authors investigated the evaluation of warning strategies in fatigue-detection systems and commented on the different possibilities and their pros and cons, including laboratory evaluations and naturalistic studies.	The development of fatigue detection technologies has received much research attention but the strategies of warning drivers has received little attention in comparison. Evaluating warning strategies is important because if a fatigued driver does not respond appropriately to the warning, there is no safety benefit in using the technology. Evaluation of warning strategies should be conducted in different contexts, laboratory studies provide the ability for researchers to control confounding variables, but they may lead to differing results compared to naturalistic settings. Therefore, despite the disadvantage of lack of control, naturalistic studies are also highly important.
Haworth, Heffernan & Horne, 1989	MUARC report	Public	The researchers assessed the involvement of fatigue in fatal truck crashes and reviewed fatigue countermeasures with a particular focus on in-vehicle devices.	19.9% of fatal crashes involving trucks between 1984 and 1986 were judged as being associated with fatigue by the researchers. In-vehicle countermeasures were considered superior to on-road countermeasures as they allow rapid detection of any sudden changes in alertness and they operate constantly. On-road countermeasures such as rumble strips may be effective but they are relatively expensive so their deployment can only be in specific high crash locations (therefore their benefit is not constant throughout a trip). In-vehicle countermeasures could be dangerous if drivers rely too heavily on these devices to alert them of when their driving is impaired. Analysis of steering patterns may be particularly valid compared to other measures while eye closure and head nodding measures may also have potential. Driver strategies such as playing alerting games need to be further evaluated. There is little evidence that introducing cold air to the driving environment will reduce fatigue, that is, unless the driving environment is particularly hot.

				An effective system will rarely produce false alarms, or give warning too late, it will not be overly intrusive and should be sensitive to all levels of fatigue (not simply extreme fatigue)
Balkin, Horrey, Graeber, Czeisler & Dinges, 2011	Journal article	Public	A comprehensive review was conducted of fatigue detection technologies, related issues, and directions for future research in the field.	The researchers listed criteria for an ideal fatigue management system including the ability to predict fatigue, measure and monitor fatigue and intervene in order to sustain alertness. Using individualised data is also beneficial in fatigue detection technologies. Challenges for the technologies were considered including the ratio of misses and false alarms and intrusiveness. Operator compliance and reliance are also issues which technologies must overcome.
Caterpillar, 2008.	Caterpillar report	Public	A detailed review on currently available fatigue detection technologies was conducted. 22 technologies were evaluated and rated in comparison to each other based on a number of categories. The pros and cons of the technologies were discussed. The review was based on the mining industry.	The top five technologies were ASTid (Pernix), FaceLab (Seeing Machines), HaulCheck (Accumine), Optalert (Sleep Diagnostics) and the Driver State Monitor (Delphi), Head nodding technologies received very low scores due to numerous false alarms and misses. ASTiD and Optalert were the only two technologies recommended by the researchers for fatigue detection.
Friswell, Williamson, & Dunn (2006)	Injury Risk Management Research Centre (UNSW) Report	Public	Compares the fatigue experiences of 1007 long distance HV drivers with 321 short haul truck drivers.	Effects of fatigue were similar for short haul and long distance drivers in terms of reported safety incidents and personal experiences of fatigue. There were clear differences in the causes of fatigue for the two types of driver. Short haul drivers worked long hours with a significant number of deliveries and pick ups, and had to deal with heavy urban traffic. Long haul drivers also worked long hours, however spent more time waiting for loading and unloading, and participated in more monotonous rural driving. The nature of fatigue-related incidents is determined by the demands of the driving environment. Rural and urban environments present different demands. Short haul drivers were less likely to view fatigue as a problem for the industry than were long haul drivers. There is a need to reduce fatigue causing factors within the short and long haul transport sectors. There is also a need to raise awareness of driver fatigue issues for short haul drivers.

Table 5.4
Sleep apnoea and related performance impairment and crashes

Authors	Type	Availability	Research	Findings
Pizza, Contardi, Ferlisi, Mondini & Cirignotta, 2008	Journal article	Public	Results of subjective and objective measures of sleepiness were related to performance on a driving simulator task by patients with sleep apnoea.	Increased objective and subjective sleepiness related to poorer performance on the driving simulator (shown in increased crashes and variability in lane position). Sleep apnoea patients were aware of their sleepiness and related driving impairment.
Pizza, Contardi, Mondini, Trentin & Cirignotta, 2009	Journal article	Public	Objective and subjective measures of sleepiness were taken and a driving simulation task was undertaken by patients with severe sleep apnoea.	Sleep-related crashes are not only due to falling asleep but also from impairments caused by sleepiness itself. In line with this, impairments in driving performance on simulator were more closely related to more general objective measures of sleepiness than those measuring patients ability to remain awake.
Tregear, Reston, Schoelles & Phillips, 2009	Journal article	Public	A review and meta-analysis of the risk of crash associated with sleep apnoea was conducted. The review focused on commercial motor vehicle drivers. The researchers also attempted to determine what factors lead to greater risk of crash within drivers diagnosed with sleep apnoea.	Sleep apnoea is particularly prevalent in commercial motor vehicle drivers. Drivers with sleep apnoea were found to be at increased risk of crash compared to those who do not have the disorder. Drivers with sleep apnoea who may be at particular risk are those with high body mass indexes, hypoxemia, greater severity of disordered breathing during sleep, and greater daytime sleepiness.
Moreno, Louzada, Teixeira, Borges & Lorenzi-Filho, 2006	Journal article	Public	Investigated the relationship between body weight and sleep patterns in truck drivers.	The researchers found that short-sleep durations are common among truck drivers because of irregular work shifts and that this decrease in sleep duration is associated with greater BMI. Obesity was associated with snoring. Truck drivers often have a poor diet and tend to be sedentary in their activities. High BMI was associated with risk of sleep apnoea
Teran-Santos, Jimenez-Gomez, Cordero-Guevara & Burgos-Santander, 1999	Journal article	Public	A case-control design was used to assess the risk of crash associated with sleep apnoea. Participants in the 'case' group were those who received emergency treatment due to a crash on Spanish highways between April and December 1995.	Sleep apnoea was strongly related to crashes, with those with sleep apnoea having a greater likelihood of crash. Even small quantities of alcohol taken on the day of the crash intensified the relationship between sleep apnoea and crashes.
Pierce, 1999	Journal article	Public	This article considered issues associated with driver sleepiness, including the causes of sleepiness and the driving-related risk associated with sleep apnoea.	Sleepiness is involved in approximately 30% of crashes. Shift work, poor quality and insufficient sleep, medications and medical conditions (including sleep apnoea) can lead to excessive sleepiness. There is a relationship between sleep apnoea and crashes. Sleep apnoea, regardless of the symptoms of excessive sleepiness, is related to an increase in risk of crash.
Charlton et al., 2004	MUARC report	Public	A comprehensive review of the relationship between chronic medical conditions and crashes was conducted. Sleep apnoea was considered among a number of other conditions.	Sleep apnoea is associated with an increased risk of car crash, largely due to falling asleep at the wheel. The severity of sleep apnoea influences the extent the condition increases crash risk, more severe apnoea leads to greater risk. It is important to identify the differences between those with sleep apnoea who have

				crashes and those that do not. CPAP therapy for sleep apnoea tends to reduce the risk of crash to that of healthy controls.
Smolensky, Milia, Ohayon & Philip, 2011	Journal article	Public	A comprehensive review of previously published literature on the relationship between sleep disorders (including sleep apnoea), medical conditions, and crash risk was conducted. Comments on the effectiveness of treatments and suggestions for the focus of future research in this field were also included.	Previous research on sleep disorders and traffic crashes have largely focused on sleep apnoea. The prevalence of sleep apnoea is likely to be much greater among professional drivers compared to the general population. Studies on sleep apnoea and crash risk largely confirm sleep apnoea is related to increased crash risk in both commercial and non-commercial drivers. Many studies investigating sleep apnoea and crashes fail to assess and evaluate the relative role of other potentially confounding variables including other medical conditions, medication use, and demographics in crash risk. Therapies for sleep apnoea including CPAP, UPPP, and OApps may be effective in reducing risk of crash due to fatigue in sleep apnoea patients. CPAP, however, has not been shown to be useful in all patients. There may be a role for medications in the treatment of patients with sleep apnoea who do not respond to CPAP treatment. Further research is required on the effectiveness and cost-benefit ratio of different therapies and treatments, particularly because CPAP has been largely focused on in the literature. The relationship between other sleep disorders and medical conditions that lead to fatigue have been relatively ignored in the literature (compared to sleep apnoea), future research should also focus on determining the involvement of these disorders and conditions in crashes, and the effectiveness of treatments in reducing crash risk. Such conditions include, narcolepsy, hypersomnia, periodic limb movement disorders, restless legs syndrome, rhinitis, asthma, chronic obstructive pulmonary disease, arthritis and chronic fatigue syndrome. The researchers also noted that the varied definitions and methods of measuring fatigue make the findings of research on fatigue difficult to compare.

Table 5.5
Substance use

Author	Type	Availability	Research	Findings
Potter (2005)	Conference paper	Public	An overview of Australian approaches to police drug and alcohol enforcement for drivers. Emphasis is placed on commercial vehicle operations.	A major component of police strategy has been a deterrence based approach to enforcement rather than mandatory workplace testing or for cause testing. Discusses the use of roadside testing procedures to reduce the incidence of drug and alcohol use by drivers. Compares the advantages and limitations of methods used in Australia and in other countries.
Couper, Pemberton, Jarvis, Hughes, & Logan	Journal article	Public	Reports the prevalence of drug use among commercial truck drivers based on assessments of 1079 drivers, 822 of whom provided anonymous urine specimens. The study was undertaken in the United States.	21% of urine specimens tested positive for either illicit, prescription, or over the counter drugs; 7% tested positive for more than one drug. The largest number of positive findings (9.5%) were for stimulants such as methamphetamine, amphetamines, ephedrine/pseudoephedrine, and cocaine. The second most common drug was cannabis (4.3%). 1.3% of drivers tested positive for alcohol.
Leyton, et al. (2011)	Journal article	Public	Reports the prevalence of drug use among truck drivers in Brazil. Of 488 drivers stopped at random 456 provided urine samples which were screened for drugs.	9.3% tested positive for drugs. Of these 61% were amphetamines, 25% were cocaine, and 12% were cannabinoids.
Mabbott & Hartley (1999)	Journal article	Public	A study of the use of stimulant drug use amongst 236 truck drivers interviewed in Western Australia.	27% of drivers reported using stimulant drugs to combat driver fatigue. Interstate driver use more prescription and illicit drugs to stay awake while intrastate drivers rely more on over the counter medications.; The most frequent methods for obtaining stimulant drugs were through a doctor, a chemist, or illegal prescription.
Williamson (2007)	Journal article	Public	An analysis of truck driver substance use to determine the predictors of stimulant drug use. Interview data collected from 970 drivers in 1991 and 1007 drivers in 2001 was used for the present study.	20-33% of truck drivers reported using stimulants at least sometimes. A significant proportion of drivers reported stimulant use as a helpful fatigue management strategy. Drivers who had the greatest problem managing fatigue were twice as likely to use stimulants. Drivers paid on a payment-by-results or contingency payment basis were 2-3 times more likely to use stimulants. Younger, less experienced drivers were also more likely to use drugs. This study demonstrates the influence of external factors, particularly productivity-based payment systems, on the stimulant drug use of truck drivers.
Richards (2005)	Thesis (Masters)	Public	Used qualitative data from 35 long haul truck drivers to better understand the substance using behaviours of truck drivers.	High rates of licit and illicit drug (particularly amphetamines) use were reported. (However the sample size for this study is rather small to generalise these findings to all heavy vehicle drivers). Some drivers begin using drugs before they begin driving trucks. Apart from fatigue motivations for drug use included peer pressure, socialisation, relaxation, addiction, and wanting to fit the trucking “image”.

5.1 Gaps in research

One of the most conspicuous gaps in research is in the area of HV driver training. No research could be found regarding the effectiveness of driver licensing and training programs or schemes. This situation is not unique to heavy vehicles and it should be noted that much research in the driver training area for road safety in general has failed to establish a connection between training and crash outcomes. Evaluation is necessary to ensure that heavy vehicle training schemes contain relevant content and follow best-practice principles.

One issue with regard to training that was raised in US research (Brock, McFann, Inderbitzen, and Bergoffen, 2007) was the use of experienced drivers as trainers with little regard to whether or not such individuals had the skills and attributes required of a good trainer.

Canadian studies of HV drivers have highlighted the importance of a minimum standard of literacy and numeracy skills for heavy vehicle drivers. This evidence indicates that training in literacy and numeracy may be required in addition to training drivers in the operation of heavy vehicles. The Australian HV industry may benefit from similar research regarding the effects of basic literacy and numeracy on HV safety.

The ecodrive training program has been demonstrated to effectively improve drivers' performance with regard to fuel economy and gear and braking inputs. A large scale evaluation of this driving method with regard to the safety benefits of ecodrive may be warranted given that it may offer a simple and cost-effective (it requires no specialised equipment and the only cost is associated with the training itself) solution for improving road safety.

Very little was found with regard to the health of heavy vehicle drivers and its influence on fitness to drive. Given that research indicates truck driving is associated with a number of health issues, including obesity, cardiovascular disease, diabetes, and sleep apnoea research into this area could provide valuable insight into the links between driver health and crashes and identify potential strategies to manage these risks.

Much of the research with regard to the impact of human factors on HV road safety focuses largely on the negative. That is, data usually relates to crash-involved drivers and the focus of research tends to be factors that cause or contribute to crash risk. A line of research that is largely overlooked involves the identification of factors that contribute to higher levels of safety, that is, what makes the safest drivers the safest drivers? This line of research may be able to inform driver training however, an inherent difficulty in such an approach lies in identifying safe drivers, a task inherently more difficult than identifying drivers involved in a crash.

The research scan has also highlighted a number of important areas with regard to sleep and fatigue that require further research. These include:

- There are inconsistencies in the evidence as to whether solo truck drivers are at greater risk of crash due to fatigue compared to team drivers.
- The effects of truck driving experience, age, and other individual differences are not consistent among studies. Further research should be aimed at clarifying these relationships in order to determine populations of truck drivers who may be at greater risk of fatigue-related crashes. Research into truck driver fatigue education and potential interventions could then be targeted at those at greatest risk of fatigue-related crashes.
- The effects and time-course of chronic sleep restriction needs further investigation, including assessment of differences in performance and recovery compared to the

effects of total sleep deprivation. These findings are likely to be more relevant to the effects of fatigue in truck drivers and may better inform drivers and the industry on the extent of rest required between shifts, particularly if these shifts are likely to restrict sleep over a number of days.

- Research investigating actions which may influence individual circadian rhythms and chronotypes may be of use in order to combat the deleterious effects of time of day and circadian phase on driving performance and fatigue. In particular, research regarding the impact of irregular shifts or driving hours on fatigue is needed.
- Sleep disorders and medical conditions causing fatigue, as well as related medications and treatments requires further research. The benefit of this research in the trucking industry will be further discussed in the section related to sleep apnoea.
- As shown, there were a number of factors likely to influence the development of fatigue, the relative importance of these factors compared to each other, in differing situations, and in interaction with each other should be evaluated. Not only may additional important risk factors for sleep related crashes be found, but factors which can be easily manipulated in comparison to other more difficult factors may be targeted to potentially create protective effects. Knowledge of the influence of additional fatigue factors could also be incorporated in efforts to predict fatigue risk or detect fatigue.
- Further research into the benefit of different countermeasures in combating fatigue would be useful in order to better inform truck drivers of effective methods and the duration of these beneficial effects. Activities aimed at fatigue reduction that may distract the driver from the primary task of driving should also be extensively evaluated, taking the potential negative effects of distraction into account.
- The evaluation of effectiveness and development of fatigue detection technologies requires further research. Evaluations should be based on a range of criteria (from reliability, validity and sensitivity, to the time and cost of the device, the ability to overcome individual differences, the flexibility of the system in different conditions, risk of data loss, and the intrusiveness of the device) and should occur in both naturalistic and laboratory settings as both have differing advantages and disadvantages.
- Fatigue prediction models require further scientific validation due to their apparent divergence from theory. These technologies may be particularly helpful in the trucking industry by informing managers of fatigue risk prior to drivers starting a shift.
- Further research should be aimed at determining the effect of different warning systems on driver behaviour.
- Further research investigating the criteria required to determine fatigue post-crash would be beneficial. Fatigue is particularly difficult to determine post-crash compared to other more obvious causes. A model and robust set of criteria for determining fatigue post-crash, particularly in crashes where the driver cannot be interviewed (such as in fatal crashes) will improve the ability for researchers to determine the prevalence and importance of fatigue. A figure which is likely to be underestimated due to difficulties in identification post-crash. Additionally, there may be fatal crashes of a particular type which are fatigue related which are often not recognised. Recognising these crashes may provide more targets for interventions as well as provide greater understanding of fatigue effects in real world conditions. Fatigue detection technologies could be beneficial in determining the relationship between fatigue and crashes when other factors are present (such as speed), however these need to be further developed before they can be relied on for this cause.

- Further research into lifestyle factors that can lead to risk of sleep apnoea. Interventions targeting lifestyle and healthy Body Mass Indexes (BMI) may reduce sleep apnoea in the trucking population and therefore reduce risk of crash due to sleep apnoea. A number of additional health benefits are also associated with healthy BMI.
- Further research into therapies and treatments (including medications) for conditions (such as sleep apnoea) that can lead to fatigue related crashes would be beneficial. This would ideally include a cost-benefit analysis of the treatments as well as potential deleterious side effects.
- The relationship between sleep apnoea and other fatigue-related risk factors should be investigated in future research, particularly as these other factors are often not evaluated in the sleep apnoea research. Determining these potential interactions will enable better understanding of the effects of sleep apnoea, and may highlight areas of potential preventative action.
- Disorders and medical conditions that lead to fatigue, other than sleep apnoea, have received relatively little attention in the scientific literature in terms of how they relate to crash risk. The prevalence of these conditions in the trucking industry as well as the risks associated with these conditions and potential treatments should be further evaluated in future research.
- Finally, collaboration between researchers from various disciplines in order to come to an improved agreement on the definition of fatigue, and/or definitions of it's subtypes, will be greatly beneficial to furthering the understanding of fatigue and it's effects.

Given the observed disparities between driver and manager perceptions with regard to the effectiveness with which fatigue is managed within the HV industry a review of fatigue management practices may be warranted. Such a review should evaluate both the process and effectiveness of fatigue management procedures.

There is scope for improving the management of substance use within the HV industry. Any effort to do so should be evidence based and guided by best practice. Research may be required to facilitate this improved management should:

- Identify the prevalence of substance use and the driver (i.e., individual) characteristics associated with substance use.
- Research is needed to determine the extent of heavy vehicle driver's knowledge of substance use and the effects these have, particularly with regard to driving performance in order to determine the most suitable intervention for reducing the impact of substance use on heavy vehicle road safety. This research may also address the feasibility of education programs or the development of a substance use knowledge network for the heavy vehicle industry.

Low levels of seat belt use among heavy vehicle occupants is concerning given the inherent safety value of seat belts. Furthermore, advances in design and improvements in ergonomics have improved the comfort and utility of these devices in many trucks. Although there is an existing body of research addressing this issue it is clear that more work is needed. Future research regarding seat belt use in heavy vehicles might include:

- Observational studies of HV occupant seat belt use would provide a more accurate indication of seat belt use rates.
- One strategy that has had some success in improving restraint use in passenger vehicles has been the seat belt reminder, a passive technology that emits a warning

light, noise, or both to remind occupants to wear a seat belt. Research should seek to address the effectiveness of such devices in heavy vehicles.

- A similar approach, the seat belt interlock, prevents the operation of the vehicle when the seat belt is not engaged. Research should seek to address the effectiveness of such devices in heavy vehicles.
- Similar strains of research may address the use of other compliance options such as the use of on-board monitoring devices and telematics.

6 Speed management and enforcement

Speed and the management of speeding vehicles is a significant issue in the area of road safety. Excessive speed in terms of driving too fast for the conditions or driving over the posted speed limit is one of the major contributing factors to crashes as identified in Table 3.1. The research presented here is concerned with issues relevant to a better understanding of HV speed issues.

Table 6.1 provides an overview of research related to HV speed and speed management. Some of the key findings to come out of this research include:

- Speeding above the posted speed limit is an issue for around 1/4 of heavy vehicle drivers with larger vehicles (e.g., B-doubles and road trains) more likely to exceed posted limits.
- Low-level speeding (within 10km/h of the posted limit) is more common than extreme speeding and as such is of more concern for overall safety outcomes.
- The speed of heavy vehicles may be influenced by other light vehicle traffic therefore, managing the speed of all vehicles has implications for heavy vehicle safety. This also has implications for the effectiveness of uniform or differential speed limits.
- Technologies such as speed limiters and ISA have safety benefits with regard to managing the speed of heavy vehicles.

Key findings in relation to the enforcement of speed and other heavy vehicle related regulations (e.g., laws regarding the mechanical condition of vehicle components such as brakes) as outlined in Table 6.2 include:

- On-board, vehicle-to-vehicle, and vehicle-to-infrastructure technologies have the potential to improve the efficiency and effectiveness of enforcement. Technology will be increasingly required to manage compliance with the growing complexity of the freight task.
- Intensive high-visibility police enforcement operations effectively reduce speeds on targeted and surrounding roads, however this effect is relatively short-lived following the cessation of police operations.
- Speed cameras have proven effective for lowering average speeds and reducing crashes on roads where they are installed.

Table 6.1
Speed and Speed management

Authors	Type	Availability	Research	Findings
Bennett, Bueker, Blanksby, & Cairney (2006)	Conference paper	Public	Describes the development of a specification for a system designed to monitor the characteristics and operation of heavy vehicles approaching a curve and to provide a warning to vehicles identified at risk of rolling over.	System characteristics were specified in terms of the vehicle and operational characteristics that should be measured, where measurements should be taken, identify the parameters indicating when a warning should be provided, and how those warnings should be delivered.
de Pont, Charlton, Latto, & Baas (2004)	Conference paper	Public	Outlines the findings of three studies measuring vehicle speeds through curves.	In the first study using data obtained from an instrumented line haul vehicle, sites of repeated high lateral acceleration were identified. The second study monitored the speeds of heavy vehicles on a number of curves with posted advisory restrictions. This enabled examinations of changes in speed behaviour and differences between vehicle types and different advisory speed levels. The third study used a simulator to investigate how speed around curves could be managed through visual cues that influence driver behaviour.
George (2003)	Austroads report	Public	Outlines the prevalence of speeding and overloading amongst Austroads class 3 and class 9 vehicles using nationwide data from weigh-in-motion devices.	17% of class 3 and 26% of class 9 vehicles were detected speeding. 2% of class 3 and 13% of class 9 vehicles were overloaded. 0.6% of class 3 and 5% of class 9 vehicles were simultaneously speeding and overloaded. For both classes of vehicle the majority of speeding was within 10% of the speed limit.
Cai, Dang, Karl, & Koniditsiotis (2010)	Conference paper	Public	Presents the IAP as a broad function of applications that is used for a range of safety outcomes & monitoring compliance.	The visibility of IAP data has achieved road safety outcomes at all levels of the transport and logistics chain of responsibility. New safety applications based on the IAP platform and utilising IAP data in conjunction with data from other sources are being developed.
Brooks (2002)	Conference paper	Public	Reviews issues relating to speed and the safety of heavy vehicles.	Concern over heavy vehicle speeds has tended to focus on the small proportion of heavy vehicles that substantially exceed posted speed limits. “Low level” speeding is important for overall safety outcomes because it is more common than extreme speeding. Total elimination of heavy vehicle speeding may prevent an estimated 25% of serious casualties involving heavy trucks. Setting speed limits and managing light vehicle speeds are other important factors that have implications for serious heavy vehicle crashes.
VicRoads & Transport South Australia	Conference paper	Public	Illustrates the heavy vehicle speeding trends since 1995 using aggregate data for various classes of heavy vehicles obtained from WIM sites across rural and urban Australia.	The percentage of heavy vehicles detected speeding is trending upwards. Larger heavy vehicles (articulated vehicles, B-doubles, and road trains) were more likely to be detected speeding. The proportion of articulated vehicles speeding was constant throughout the day. Rigid vehicles were more likely to speed between 6am and 6pm.

				B-doubles were more likely to speed between 6pm and midnight.
AMR Interactive (2006)	NTC research paper	Public	An evaluation of 619 heavy vehicle drivers' knowledge, attitudes, beliefs, and reported behaviours with regard to speeding.	The most important factors associated with risk taking were attitudes about the acceptability of speeding. A number of issues regarding the development of strategies to address heavy vehicle speeding were also discussed. These include: general attitudes, situational triggers, promotion of enforcement, new technology, and penalties.
Truong, Fitzharris, Stephan, Healy, Rowe, & Collins (2010)	Conference paper	Public	Reports on the preliminary findings of a small-scale trial of ISA on heavy vehicles.	Discusses the merits of ISA in terms of speed choice, fuel consumption, and driver acceptability.
Saccomanno, Duong, Cunto, Hellinga, Philip, & Thiffault (2009)	Journal article	Public	An investigation of the safety implications of mandated truck speed limiters using a microscopic simulation approach.	Truck speed limiters produced positive safety gains for different assumed volumes and percentages of trucks and different compliance levels. Under some conditions, e.g., high volumes and high percentage of trucks, speed limiters produced a reduction in safety.
Garber, Miller, Sun, & Yuan (2006)	Journal article	Public	An examination of the safety benefits of differential speed limits for cars and trucks based on statistical comparisons of crashes between (US) states with uniform or differential speed limits.	Aggregate results showed no consistent safety effects of DSL as opposed to USL. This was due to an increased crash risk observed for each state over the period of data collection (1991-2000).
Friswell, Irvine, & Williamson (2003)	Journal article	Public	Examines the distribution and patterns of speeding of heavy vehicles using data collected from 20 fixed speed camera sites in rural and urban NSW.	HVs were less likely to be detected for speeding compared to LVs. In 110 km/h zones HVs tended to speed as much as LVs, which appeared to be in response to the upper speed limit for LVs rather than the lower speed limit for HVs. Speed-related crash rates were lower for HVs, particularly on country non-urban roads.

Table 6.2
Enforcement

Authors	Type	Availability	Research	Findings
Carden, Hughes, Deedy, Yeakel, & Keppler (2005)	Conference paper	Public	Describes the use of active and passive communications between commercial vehicles and infrastructure to assist with enforcement and improve security for commercial vehicles.	Vehicle to infrastructure communication is considered a basic component of North Carolina's concept of enhanced commercial vehicle enforcement for both safety and security. Information that could be communicated to static and mobile infrastructure include vehicle diagnostic information, driver status (e.g., hours of service, fatigue, etc.), and other information critical to security, such as driver ID authentication and evidence of load tampering.
Urbanik (2005)	Conference paper	Public	Describes the initial phase of a concept, called Trusted Truck, for improving the safety, efficiency, and security of the truck inspection process.	Demonstrates the real-time capability to provide brake condition data to a roadside inspection station at highway speeds through the use of wireless communications.
Soole, Watson, & Lennon (2009)	Conference paper	Public	A quantitative survey investigating the impact of police speed enforcement methods on self-reported speeding behaviour of 852 Queensland drivers.	Visible enforcement was associated with greater self-reported compliance than were covert operations and the effects on behaviour were long-lasting. The mobility of police operations had differing effects for covert and overt operations. Covert: mobility associated with increased self-reported compliant behaviour. Overt: Increased longevity of reported compliant behaviour.
Walter, Broughton, & Knowles (2011)	Journal article	Public	An investigation of the effects of increasing police traffic enforcement in a busy urban area. Operation Radar ran for four weeks and increased police visibility in the area.	Roadside surveys revealed that speeds reduced systematically during the operation along the targeted route and in surrounding areas. Some effects were observed to last at least two weeks beyond the operational period. No positive effect of the operation on the use of seat belts or mobile phones were observed.
Vaa (1997)	Journal article	Public	Assesses the effectiveness of increased police enforcement on speed. Speeds were measured before, during, and after a six week period of increased police enforcement on a 35 km stretch of road with 60 and 80 km/h posted limits. Speeds were also compared to another stretch of road.	Average speeds were reduced by 1-5 km/h in both speed-limit zones and for all times of day. For some time periods the percentage of speeding drivers were reduced for up to eight weeks after the increased police presence was withdrawn. The percentage of speeding drivers was reduced for both speed-limits and for all hours of the day with the exception of the peak morning traffic (6-9am). Drivers in the morning rush hours appear most resistant to speed reduction.
Hakkert, Gitelman, Cohen, Doveh, & Umansky (2001)	Journal article	Public	Assesses the effectiveness of the deployment of Israel's national traffic police in a general enforcement on 700km of interurban roads where 60% of all rural accidents and half of all severe accidents occurred.	A general reduction in traffic violations was observed during the operation, with the exception of compliance with stop signs and turn signalling.

			Involved observations of speed before and during the project (which ran for one year) and driver surveys of perceived police presence and enforcement effectiveness.	Driver surveys revealed improvements in the perceived level of police activity, however drivers perceptions of risk of apprehension for violations remained unchanged. Statistically significant reduction in severe accidents and severe casualties were achieved on highly enforced roads in the centre of the country compared to other roads. Examination of project implementation revealed police required more flexibility in terms of deployment and enforcement tactics and procedures.
Newstead, Cameron, & Leggett (2001)	Journal article	Public	Reports on the effects of a resource management technique (Random Road Watch) that randomly schedules low levels of police enforcement in a manner designed to provide wide-spread and long-term coverage of a road network in Queensland.	Analysis of the effects of the Random Road Watch program demonstrated that the program effectively reduced crashes in the areas covered by the program. The largest effects were observed for fatal crashes with an observed reduction of 31%. Overall the program produced an 11% reduction in crash totals outside of metropolitan Brisbane.
Goldenbeld & van Schagen (2005)	Journal article	Public	An evaluation of a targeted speed enforcement program involving mobile radar on rural non-motorway roads in the Dutch province of Friesland. Speed data for the roads covered by the program were evaluated for each year of the program's five year duration.	A significant decrease in the mean speed and the percentage of speeding violations was observed over the five year period. The largest decreases were observed in the 1st and 4th years of the project when enforcement was at its highest. Spill-over effects were observed in the reductions in speeding on nearby comparison roads that were not included in the enforcement project. It was estimated that the project reduced both the number of injury crashes and the number of serious casualties by 21%.
Shin, Washington, & van Schalwyk (2009)	Journal article	Public	An evaluation of the effectiveness of a fixed-camera speed enforcement program undertaken on a 6.5 mile urban freeway in Scottsdale, Arizona. The program had a duration of nine months.	Average speeds in the enforcement zone were reduced by 9mph during the program. All crash types, with the exception of rear-end crashes, were reduced. Speeding detection frequencies increased by a factor of 10.5 after the program was temporarily terminated. The annual safety benefits of the program were an estimated $17 million.
de Waard & Rooijer (1994)	Journal article	Public	Research undertaken to determine the most effective method of police enforcement to reduce driving speed and optimise the use of police personnel. Speed was measured before, during, and after the trial of two different approaches to enforcement. Surveys were used to obtain driver opinions about speeding and enforcement.	The highest intensity level of police enforcement yielded the largest and longest lasting reductions in driving speed. Stopping offenders was found to be a more effective means to reduce driving speed than mailing of fines. Driver surveys indicated that many drivers did not notice the recurrent enforcement due to infrequent use of the targeted roadways. The preventive effect of enforcement appeared to be more substantial than its repressive effect.

				Enforcement was found to primarily deter current *non-offenders* from speeding.
Bjornskau & Elvik (1992)	Journal article	Public	Adopts a game theory approach to understanding and explaining outcomes of police traffic enforcement practices.	The main implications derived from game theory are: 1. Most attempts at enforcement will not have a lasting effect on driver behaviour or crashes. 2. Imposing stricter penalties will not affect road user behaviour. 3. Imposing stricter penalties will reduce the level of enforcement 4. Implementing automatic surveillance techniques or the allocation of enforcement resources according to a chance mechanism (and not according to police estimates of violation probability) can make enforcement effects last.
Mountain, Hirst, & Maher (2005)	Journal article	Public	An evaluation of the impact of different speed management schemes on traffic speeds and crashes.	When judged in absolute terms all types of speed management schemes had similar effects on crashes. Engineering schemes utilising vertical deflection (e.g., speed humps and cushions) provided twice the safety benefits (in terms of crash reduction) of safety/speed cameras (44% v 22%).
Beenstock, Gafni, & Goldin (2001)	Journal article	Public	Panel data to investigate the effect of traffic policing on rural road accidents in Israel was used.	Only large scale enforcement was found to have any effect on crashes; small-scale enforcement was found to have no apparent effect. Enforcement effects were found to be larger in the long-run rather than short-term. Effects of enforcement were found to dissipate rapidly when the level of enforcement is reduced. Enforcement was found to have no effect on fatal crashes. Evidence of enforcement on one road spilling over to other roads was weak.
Loader (2006)	Austroads report	Public	Presents guidelines for a nationally consistent implementation of legislative provisions of the Road Transport Reform (Compliance and Enforcement) Bill relating to load restraint breaches.	Introduces risk-based categorisations of breaches based on load and restraint characteristics and the threat that breaches of accepted standards pose to immediate safety.
Keogh (2002)	Conference paper	Public	Outlines the role of enforcement in heavy vehicle compliance and safety and identifies future directions with regard to the role of enforcement agencies in improving heavy vehicle safety.	Enforcement resources are limited, thus it is important to maximise the effectiveness of these resources. Enforcement is only one component of compliance, however without enforcement it is unlikely that improvements in compliance and safety will be achieved. A cooperative approach by all participants in the heavy vehicle industry is required for the achievement of successful outcomes.
Honefanger, Strawhorn, Athey, Carson, Conner, Jones, et al. (2007)	Report	Public	A research scan of international technologies used in the enforcement of commercial motor vehicles weight and size.	European countries use a range of technologies to improve the effectiveness and efficiency of size and weight enforcement.

Taylor & Opiola (2003)	Conference paper	Public	Describes the elements and requirements necessary for a robust electronic compliance monitoring system for heavy vehicles.	Traditional methods of ensuring compliance will not keep pace with the increasingly complex road transport task. An electronic compliance monitoring system needs to ensure its own internal integrity and supply of irrefutable evidence of non-compliant behaviour.
Wilson, Willis, Hendrikz, Le Brocque, & Bellamy (2011)	Cochrane review	Public	A review of 35 studies evaluating the effect of speed cameras on speeding, crashes, injuries, and deaths. All studies assessed the above before and after the introduction of speed cameras, and comparing these findings with comparable roads with no speed camera enforcement.	All studies in the review reported reductions in average speeds following the introduction of speed cameras. Reductions in speeding vehicles ranged from 8% to 70% with most countries reporting reductions in the order of 10-35%. Of the 28 studies that measured the effect on crashes 100% found a reduction in the number of crashes following the implementation of the speed camera program. Consistency of the reported findings demonstrate that speed cameras are a worthwhile intervention for reducing the number of road traffic injuries and deaths.
Regher, Montufar, Sweatman, & Clayton (2010)	Conference paper	Public	Exposure based evidence to assess the regulatory compliance of long truck operations in the Canadian Prairie Region was used.	Analysis indicated that 99% of observed long trucks were compliant with the undivided highway network restriction and prescribed weight limits. Using exposure-based collision rates to determine safety compliance, available evidence indicated that long trucks had a lower collision rate than other articulated trucks.

6.1 Gaps in research

With regard to heavy vehicle speeding, speed management, and enforcement there are a number of areas that would benefit from further investigation. These are discussed below.

The majority of general enforcement literature is concerned with the speed of all road users. There is no real indication of the effectiveness of different enforcement strategies on the speeding behaviour of heavy vehicles. Research could identify the most effective strategies for heavy vehicle enforcement in rural and urban locations.

Effectively managing and enforcing the speeding behaviour of light vehicles appears to be another means for moderating the speeds of heavy vehicles. Point-to-point technologies could have benefits that are yet to be identified if utilised in the management and enforcement of all motor vehicles.

Identifying the factors that contribute to a heavy vehicle driver's motivations for speeding may identify a number of driver, employer, or industry factors that could be used to better manage speed compliance. For example, should the majority of drivers speed in order to meet scheduling and delivery requirements, measures to address these issues may offer both simple and effective means for managing heavy vehicle speeds. Investigating ways to improve general knowledge on ecodriving, scheduling or trip planning skills would be beneficial to the industry as a whole.

Large scale evaluations of the effects of ISA and other speed management technologies are warranted and are likely forthcoming in the future as uptake of the technology increases.

The advent and capabilities of new technologies are changing the face of enforcement. This has a number of implications that may need to be addressed including how these technologies will be used by enforcement agencies and the development of minimum performance requirements with regard to the evidentiary suitability of data. Finally it will also be necessary to reassess existing enforcement practices and (possibly) the penalties associated with breaches.

7 Accreditation schemes

Safety accreditation schemes provide an alternative means for ensuring heavy vehicle operator compliance with recognised safe operating standards. These standards address a range of issues including fitness to drive and driver health, training, vehicle maintenance, and the management of transport operations. Table 7.1 provides an overview of the evidence regarding the effectiveness of accreditation and regulation schemes. Some of the key findings include:

- Accreditation schemes such as TruckSafe and the National Heavy Vehicle Accreditation Scheme have improved the safety of heavy vehicle operations. Evidence shows that accredited heavy vehicles have a lower crash risk when compared to non-accredited heavy vehicles.
- Accreditation schemes provide an effective means for setting minimum standards for safe operating procedures.
- There appears to be support for accreditation schemes throughout the industry with a number of accredited operators indicating that the benefits of accreditation outweigh the costs. Indeed a number of reports indicate accreditation benefits the productivity of the organisation however, the true nature and extent of these benefits have not been fully determined.

The advent of heavy vehicle accreditation schemes provide an indication of both the national government's (the NHVAS) and heavy vehicle industry's (the ATA's TruckSafe) active involvement in improving the safety of the heavy vehicle industry.

Another development that may prove beneficial to the heavy vehicle industry is the promotion of road safety charters amongst organisations. Such charters encourage companies to become "good corporate citizens" and raise their standards in relation to road safety practices and culture. The European Road Safety Charter, an initiative of the European Commission, provides a good example of the potential for these schemes to involve a broad range of stakeholders (ERSC, 2011).

Table 7.1
Effectiveness of accreditation and regulation schemes

Authors	Type	Availability	Research	Findings
Walker (2010)	Conference paper	Public	Examines the Australian experience with regulatory accreditation and its role in providing greater policy responsivity to changing industry demands.	Draws on the experiences of heavy vehicle operators, industry associations, and regulators and examines the potential for the development of a 2-track regulatory system that balances the need for policy flexibility for industry bodies and effectively manages risks to the community.
Baas & Taramoeroa (2008)	Austroads report	Public	Seeks to determine the safety benefits of heavy vehicle accreditation schemes.	Accreditation provides a formal process that recognises operators who have good safety and management systems for vehicle maintenance, driver fatigue, and vehicle loading. On average vehicles accredited to TruckSafe or the NHVAS had 50% and 75% fewer crashes respectively than non-accredited vehicles. Operators perceived the benefits of accreditation as outweighing the costs. Operators were found to improve through the process of becoming accredited. Greater use of accreditation schemes should be encouraged as they are amongst the most effective means for advancing heavy vehicle safety.
National Transport Commission (2006)	Discussion paper	Public	Due to numerous policy changes and developments since the inception of the National Heavy Vehicle Accreditation Scheme, analysis was undertaken to determine the safety benefits from accreditation. Analysis involved a comparison of the crash rates for accredited versus non-accredited operators between 2003 and 2005.	Non-accredited vehicles had a crash rate around 2.5 times higher than accredited vehicles.
Leyden, McIntyre, & Moore (2004)	Conference paper	Public	A paper providing an overview of Australian approaches toward improved compliance with heavy vehicle mass limits and the role of heavy vehicle accreditation schemes in mass compliance and enforcement.	Discusses the role of accreditation schemes in assisting operators with duty of care and for providing evidence that chain of responsibility obligations have been met.
Ironfield & Moore (2002)	Conference paper	Public	Examines the approaches to regulation of the road freight sector used in Australia and other developed countries with a discussion of the effectiveness of operator licensing schemes.	Innovative regulatory approaches adopted in Australia include accreditation-based compliance, the implementation of chain of responsibility, and enhanced compliance through improved enforcement and evidentiary provisions. The major element of regulation in most other developed countries focuses on the maintenance of extensive operator licensing.
Taylor (2000)	Conference paper	Public	Describes the principles of alternative compliance used in the development of the NHVAS and outlines the role of alternative compliance in achieving national compliance.	A national approach to alternative compliance has been achieved. Factors that may impact alternative compliance in the future include advancement in technology, chain of responsibility, and duty of care. The underlying principles of alternative compliance provide industry and government with a means for improving the management of compliance at a national level.

McIntyre (2005)	Conference paper	Public	Outlines the Australian national compliance reforms and demonstrates how these have the potential to reduce heavy vehicle fatalities through increased compliance and accountability.	The chain of responsibility is at the heart of these reforms. New compliance and enforcement legislation make the concept of chain of responsibility more effective.
Chen (2008)	Journal article	Public	A study of the impact of compliance reviews on reviewed trucking companies in reducing truck crashes.	Companies that received compliance reviews had a higher crash rate than never reviewed companies. Reviewed companies experienced a 15-39% reduction in crashes in the year following the review. The reduction in crashes was sustained for at least 7 years following the review.
Wright, Veith, & Tsolakis (2005)	Austroads report	Public	Attempts to determine the safety benefits achieved by companies due to improving the safety of their operations, and driver safety in particular. Qualitative data was obtained from 12 companies with operational safety programs.	Companies reported improved driver attitude and vehicle maintenance benefits, savings in insurance costs, and improved fleet utilisation. Other benefits included greater flexibility in the use of drivers and reduced costs due to injury. Australian trucking companies are increasingly employing programs that focus on fatigue management, driver training, and the efficient use of fleets. While some companies claim some productivity benefits associated with these programs there is a lack of rigorous evaluation to assess the true nature and extent of these benefits.
Mooren & Grzbieta (n.d.)	Report	Public	A review of the NHVAS and TruckSafe safety accreditation programs to determine the cost effectiveness of these for assuring the safety of heavy vehicles.	Alternative compliance programs such as TruckSafe and NHVAS have the potential to assure optimal safety for accredited heavy vehicle operations.

7.1 Gaps in research

Evidence indicates that accreditation improves the safety of accredited heavy vehicle operations, including reductions in crash risk. There would appear to be a number of benefits to be derived from increasing the number of accredited heavy vehicle operations. In keeping with this there are a number of research options that may inform strategies for improving upon existing accreditation rates. Research quantifying the nature and value of the benefits associated with accreditation may be used to improve the profile of accreditation schemes and provide non-accredited organisations with tangible evidence of improved safety and productivity their operation could achieve through accreditation.

A further line of research should attempt to identify the barriers for adopting accreditation. Such research should consider, amongst other issues, differences in accreditation rates by operation size and type (e.g., type of cargo, short haul vs long haul, etc.). A better understanding of why heavy vehicle operators are not accredited will enable the development of strategies to address those barriers and improve existing accreditation rates.

8 Overview and conclusions

This section is intended to provide a general synthesis of the evidence gleaned from this research scan. Recommendations are made with regard to potential research areas that have the potential to offer cost-effective improvements to heavy vehicle road safety.

Currently, leading road safety nations have adopted a systems based approach to road safety which is based on the principle that road users make mistakes and that the road system needs to better accommodate these mistakes when they occur. Governments will be using the Safe Systems approach to road safety when considering heavy vehicle road safety over the next decade.

8.1 Heavy vehicle crashes

Investigations of HV crashes provide valuable information regarding the characteristics and causes of these crashes. These statistics and research indicate that single vehicle crashes, particularly loss of control type crashes (e.g., run off road and rollover), account for the majority of HV crashes. The key causal factors of these crashes include inappropriate or excessive speed and fatigue. The mechanical condition of the vehicle and the characteristics and distribution of the load also influence these crash types. Statistics also indicate that articulated HVs are more often involved in crashes than rigid HVs. This is likely due to differences in the transportation tasks for which these vehicles are used. Articulated HVs are used for long haul interstate transportation involving long working hours and greater travel distances in rural areas, whereas rigid HVs are more commonly used for short haul purposes in urban locations.

The characteristics of HV crashes are well researched and documented however continued observations of HV crash trends over time should be maintained. There is a bias towards investigating severe HV crashes and there would also be benefit in researching minor HV crashes to determine why more serious outcomes did not occur.

8.2 Road and vehicle design

It is clear that there are certain design features of a road that present safety issues for HV drivers. However, treatments such as the sealing of shoulders along HV routes offer a simple and cost effective means to address these risks. A further means for reducing the risks associated with road design features can be addressed by vehicle design and vehicle technologies. On-board warning systems can be used in conjunction with ITS to forewarn drivers of potential hazards allowing them to take proactive steps to reduce those risks. For example, warning drivers that their speed may be inappropriate for an upcoming bend will enable them to slow to a more appropriate speed before entering the curve. ISA technologies can further reduce HV risks associated with speed. Other technologies such as ESC, VSS, YSC, and EBS that improve the stability and control of the vehicle under everyday or emergency driving conditions also have the potential to improve HV safety. Digital short range communications (DSRC) also hold significant potential for improving the operational safety of all vehicles on the road network.

The design of HVs are such that they have high aggressivity, which presents significant risk to other road users, and varied crash worthiness, which can present a risk to the HV driver. Improvements in either or both of these areas through design or manufacturing processes would produce safety benefits.

8.3 Human factors and social

Fatigue is an issue of primary concern for the HV industry, particularly among long haul drivers. A number of advances in knowledge and management of fatigue and fatigue issues have been made however, there is clearly more to be done (see section 4.1). Perhaps one of the most significant findings of this scan (with regard to fatigue) is the apparent discrepancy between drivers and managers with regard to the effectiveness with which fatigue is managed. It would appear that fatigue management strategies are in place however, the reality of the manner in which these are executed or maintained under the real world pressures of scheduling and the drive for increased productivity appears to limit their effectiveness.

There are a number of general and mental health issues (including substance use) associated with HV safety that are at least as common among HV drivers as amongst the wider Australian population. Effectively addressing these issues would be of value for the HV industry and all other road users and also improve the general well-being of HV drivers themselves.

8.4 Speed management and enforcement

The evidence outlined within this research scan indicates that speed is an issue for heavy vehicle safety. Due to the proportions involved, low level speeding amongst HVs remains a significant safety issue. Speed limiters and ISA offer safety benefits with regard to the management of HV speed.

Police enforcement campaigns play an important role in affecting the behaviour of all road users. Evidence indicates that a variety of strategies produce a number of safety benefits. High visibility operations effectively reduce speeds on targeted roads and, to a lesser extent, surrounding roads, although this effect is relatively short lived following the cessation of police operations. The immediacy of enforcement appears to further influence the effectiveness of enforcement strategies with immediate punishment (i.e., stopping a driver detected breaking the law) having a greater effect than delayed punishments (i.e., receiving a fine in the mail). This does not suggest however that delayed punishments have no effect as research has demonstrated that speed cameras are also an effective means for lowering average speeds and reducing crashes on roads where they are installed.

With regard to managing compliance with the many regulations that govern HV operations throughout Australia the advent of telematics, and vehicle-to-vehicle and vehicle-to-infrastructure technologies appears set to improve the efficiency and effectiveness of enforcement.

Research into HV specific enforcement would be beneficial to determine the safety effects of differing enforcement strategies, especially in relation to speed.

8.5 Accreditation schemes

The success of accreditation programs has been determined by comparing the crash rates of vehicles from accredited operations to those from non-accredited operations. Such studies have demonstrated positive safety benefits of accreditation schemes. Accreditation, it would appear, also offers a number of benefits for productivity although these are yet to be adequately quantified.

8.6 Recommendations for future research

Throughout this research scan a number of knowledge gaps have been identified as potential targets for future investigation. Recognising that it is impractical to embark on a research program addressing each of the areas identified in this scan it is suggested that a program of research addressing the following areas, in no particular order, offer the most benefit to heavy vehicle road safety.

8.6.1 Fatigue

Fatigue is a clear issue for the heavy vehicle industry. Any research with the potential to improve the way in which fatigue is managed within the HV industry should be encouraged. Research that further helps identify HV drivers who may be at greater risk of fatigue-related crashes would assist this process.

8.6.2 Seat belts

Indications of the seat belt use of heavy vehicle drivers suggest that compliance with seat belt use is low with estimates ranging from 4-30% (Haworth, Bowland, & Foddy, 1999; Symons, 2004). Estimates of the benefits of increasing seat belt use among heavy vehicle drivers would effectively prevent 37% of fatalities, 36% of serious injuries, and 22% of slightly injured truck occupants (Simon & Botto, 2001). Research to improve seat belt use among heavy vehicle occupants should seek to establish the prevalence of seat belt use by HV occupants and identify the reasons that influence HV occupants' use of seat belts.

8.6.3 Road design and traffic management

International research indicates that lane and speed restrictions for HVs on some road sections have positive effects for road safety in these areas. Research should evaluate the effectiveness of such strategies under Australian conditions. This research could also investigate the effect of these restrictions on traffic flow and productivity of the HV industry.

8.6.4 Technology

Numerous technologies have been developed with potential safety benefits for HVs. Evaluations of the effectiveness of these technologies will assist the HV industry in the identification of those technologies that offer the greatest benefits for HV safety. Such research is important given the rate at which existing technologies evolve and new technologies are developed. It is also important to identify ways in which the most at risk HV drivers benefit most from these technologies.

8.7 Closing comments

This heavy vehicle road safety research scan has demonstrated the extent to which the heavy vehicle industry, government agencies, and research professionals are committed to improving heavy vehicle road safety world-wide. Within Australia, a number of stakeholders are actively committed to the advancement of heavy vehicle road safety through the development of policy, regulation, and support of research. This research scan represents the active steps taken by a key industry body, the Australian Trucking Association, to guide the strategic direction, future development and improvement of heavy vehicle safety.

Acknowledgements

This research scan was commissioned by the Australian Trucking Association (ATA). ATA input was provided by Bill McKinley and Jodie Broadbent.

The Centre for Automotive Safety Research is supported by both the South Australian Department for Transport, Energy and Infrastructure and the South Australian Motor Accident Commission.

The views expressed in this report are those of the authors and do not necessarily represent those of the University of Adelaide or the funding organisations.

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