



DESKTOP REVIEW OF CONSPICUITY MARKINGS FOR HEAVY VEHICLES

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1. BACKGROUND

Heavy vehicle crashes are a significant contributor to road trauma in Australia and in other countries. The Centre for Accident Research and Road Safety – Queensland (CARRS-Q) was commissioned by 3M to examine currently available research into the effectiveness of heavy vehicle visibility markings in reducing crash involvement and its relevance for Australia.

A desktop review of the available literature was undertaken and an attempt made to describe the potential benefits in terms of crash reductions under Australian conditions.

2. METHODOLOGY AND DEFINITIONS

A search of the academic and professional literature was undertaken to identify pertinent studies. The search engines used were Google Scholar, Science Direct, and the QUT library quick find advanced search. The search terms were: Heavy vehicle safety AND visibility OR conspicuity; truck safety AND visibility OR conspicuity. In addition, 3M supplied a range of reports that they have sourced internationally. The results of the literature search were examined, particularly in terms of relevance to Australian conditions.

Data on fatal heavy vehicle crashes in Australia were obtained from the Australian Road Deaths Database.¹ Data on heavy vehicle usage including distance travelled and numbers of vehicle registrations were obtained from the *Australian transport statistics yearbook 2009* (BITRE, 2009).

The review draws on information from a wide range of sources and jurisdictions, and some comparisons must be viewed cautiously as the results are derived from different datasets with different inclusion criteria. The definitions of heavy vehicles and the scope of crashes included vary among data sources. For example, the recent Australian report into major truck crashes by Driscoll (2011) includes crashes of trucks with a **payload** exceeding 5 tonnes which resulted in substantial vehicle insurance claims. Some of the crashes included in that report may not have resulted in injury. In contrast, BITRE has defined ‘rigid’ trucks as having a **gross vehicle mass** (GVM) equal to or greater than 3.5 tonnes, and ‘heavy vehicles’ as having a GVM equal to or greater than 4.5 tonnes (BITRE, 2003) (thus, according to these BITRE definitions, heavy vehicles do not include all rigid trucks). In the US, the NHTSA has reported on the effectiveness of conspicuity markings (retroreflective tape) on heavy trailers (Morgan, 2001), which by definition have a ‘Gross Vehicle Weight Rating over 10,000 pounds’ (4.54 tonnes), a measurement which excludes the prime mover. Requirements for European trucks and trailers also refer to weight categories, where the ECE 104 Regulation specifies marking for vehicles exceeding 7.5 tonnes gross vehicle weight. The European requirements may vary according to adoption by individual countries. In Australia, the current requirement for rear marking plates refers to vehicles with a GVM over 12 tonnes and trailers over 10 tonnes (GTM). In addition, different colours are specified for retroreflective markers in different jurisdictions. In the US they are a red/white combination, in Europe white and/or yellow (red replaces white on the rear), and yellow/red in Australia.

Retroreflection has been defined as ‘the process of returning light back to its source’ (King, 2010, p. 2). As such, retroreflective markings on vehicles rely on a light source from elsewhere, such as vehicle headlights, to illuminate the marking. The efficiency with which reflection is achieved (luminance) and the angle from which a material reflects depends on the design and composition of the material, which has generally improved over time through research and development. Classes of retroreflective materials are specified in the Australian Standard covering road signage (AS1906), wherein the classes of materials specified are the same as used for vehicle conspicuity markings in Australia. These include Class 1W (wide-angle), 1A, 1, 2A and Class 2 materials, with Class 1 materials reported to have approximately four times higher reflective properties than Class 2. Class 1 materials have higher photometric properties, are able to reflect at greater angles (particularly Class 1W), and their effectiveness is less compromised by dirt on the plate surface compared with their Class 2 counterparts (King, 2010; Main Roads WA, 2011; WorkSafe, 2005).

¹ http://www.infrastructure.gov.au/roads/safety/road_fatality_statistics/fatal_road_crash_database.aspx

King (2010) also describes fluorescent materials, which use selected pigments to absorb specific invisible ultraviolet rays from sunlight and convert them into visible light. The result is an emission of a greater amount of light from a fluorescent coloured material than a non-fluorescent one, thus increasing visibility, particularly in situations of limited light such as dawn, dusk, and heavily shaded areas, though not in darkness. The use of fluorescent materials combined in retroreflective sheeting is reported to enhance daytime visibility (TUV Rheinland Group, 2004), complementing the night time benefits of retroreflective material, and is increasingly used in signage and other retroreflective material applications.

3. IMPORTANCE AND CHARACTERISTICS OF HEAVY VEHICLE CRASHES

In Australia in 2010 there were 190 fatal crashes involving heavy rigid and articulated trucks², resulting in 225 deaths. There were a further 20 fatal bus crashes resulting in 21 deaths. These fatalities represented 18.2% of the total 1,352 road deaths in Australia in 2010.³ Trucks were involved in the same proportion (18%) of fatal and injury crashes in Australia in previous decades according to an early report by Rechnitzer (1993), suggesting that their contribution has remained stable over time.

As can be seen in Figure 1, the total number of fatal heavy vehicle crashes per year has declined in Australia since 2002 (the first year for which rigid truck data are available in the database), when there were 270 fatal heavy vehicle crashes.⁴ For the five years from 2002 to 2006, fatal heavy vehicle crashes averaged 248 per year, while the yearly average for the following four years (2007-2010) was 7% lower at 231. Most of this decline is attributable to fewer crashes involving articulated trucks, and to a lesser degree buses, while fatal rigid truck crashes did not decline over the nine year period.

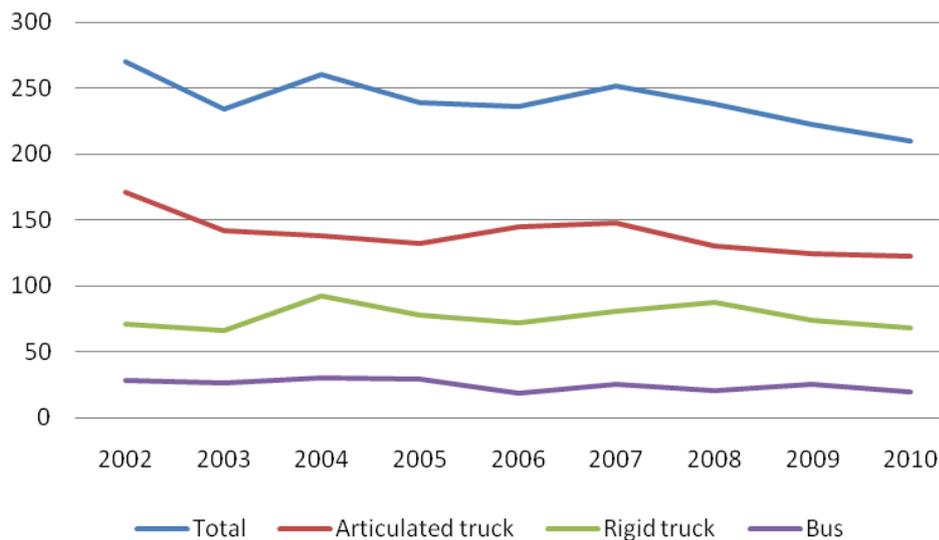


Figure 1: Fatal crashes involving heavy vehicles, Australia 2002-2010

There are differences in the rates of fatal crashes by truck type (articulated and rigid), as indicated below in Table 1. The Australian Road Deaths database indicates a fatal crash rate of 0.9 per 100 million VKT for rigid trucks in 2008, compared with 1.8 per 100 million VKT for articulated trucks. Haworth and Symmons (2003) reported similar results for 1997, although the crash rate had declined somewhat over the following decade. While Table 1 only presents fatal crash data, there are also differences in crash severity by truck type according to the literature, as discussed in following sections. In fatal crashes in Australia, it can be seen that articulated trucks are overrepresented in fatal crashes relative to their share of registrations and, to a lesser extent, their share of distance travelled (exposure).

² Articulated trucks include prime movers with single trailers, B-doubles and road trains (BITRE, 2003).

³ Data obtained from Australian Road Deaths Database.

⁴ Involving articulated trucks, rigid trucks or buses, as defined for the Australian Road Deaths Database.

Table 1: Fatal crashes, registrations and distance travelled as proportion by truck type⁵

Truck type	Fatal crashes <i>N</i> = 444 (2 cal years, 2007-08)	Registrations (1 fin year, 2007-08)	Distance travelled (1 fin year, 2007-08)
Articulated	62%	16%	44%
Rigid	38%	84%	56%

Australia-wide information about heavy vehicle crashes in which injuries but not fatalities occur is relatively scarce. The Australian Institute of Health and Welfare publishes data on persons admitted to hospital from road crashes (Henley & Harrison, 2009). In the financial year 2006-07, 892 people were admitted to hospital after a multi-vehicle or pedestrian-vehicle crash in which the collision partner was a heavy transport vehicle or bus. This comprised 2.7% of persons hospitalised from road crashes. An additional 411 occupants of a heavy transport vehicle were hospitalised from road crashes. If the crashes in which no other vehicle was involved were removed, then the total drops from 1,303 persons to 903. It is appropriate to exclude single vehicle crashes from consideration in the current report as these crashes are highly unlikely to be related to vehicle conspicuity.

The comparison of the hospital data with those for fatalities presented earlier underlines the greater severity of heavy vehicle crashes in that they contribute a larger proportion of fatal than hospitalisation outcomes (about 18% versus 3%). NSW data for 2010 shows that 2% of reported heavy rigid truck crashes and 4% of articulated truck crashes resulted in a fatality, compared to 1% of car crashes.

The crash data and associated trends need to be considered in the context of increased heavy vehicle usage and activity. For articulated and rigid trucks combined, from 1998 to 2008 there were strong increases in the annual total vehicle kilometres travelled (22.6%), total stock of registered vehicles (14.5%), and road freight in billion tonne kilometres (45.2%) (BITRE, 2009). These statistics indicate that although heavy vehicle safety has improved only slightly in the last decade as measured by the number of annual fatalities, the improvement in the safety of heavy vehicles relative to exposure (i.e. increased usage) can be considered a positive outcome.

3.1 Relevance of conspicuity in heavy vehicle crashes

As a step towards assessing the potential benefits of improved heavy vehicle conspicuity, an examination of the characteristics of crashes was undertaken. It is assumed here that improved heavy vehicle conspicuity will be of no benefit in crashes involving only the heavy vehicle and of negligible benefit in crashes involving a heavy vehicle and a pedestrian but no other vehicle. It is also highly likely that improved heavy vehicle conspicuity will be of most benefit at night and in other low light conditions (e.g. twilight, fog and heavy rain), and of lesser benefit during the day. For this reason, Australian heavy vehicle crash data were examined in relation to the vehicles involved, time of day and atmospheric conditions.

The proportion of heavy vehicle crashes that involve multiple vehicles appears to vary as a function of severity. More than two thirds (71%) of fatal crashes involving heavy vehicles in

⁵ Crash data from Australian Road Deaths Database, registration and distance data from BITRE (2009)

Australia over the five years to September 2010 were multi-vehicle crashes (BITRE, 2010). NSW data for heavy truck crashes found that 78% of all recorded crashes involved multiple vehicles, while only 64% of fatal heavy truck crashes involved multiple vehicles (NSW Transport, 2011). In contrast, insurance data for crashes with an aggregate cost of more than \$50,000 involving trucks with a payload of more than 5 tonnes shows that most are single vehicle crashes (Driscoll, 2011).

Given that most fatal heavy vehicle crashes involve more than one vehicle and that the heavy vehicle is much larger than the other vehicle, it is not surprising that the majority of persons killed in heavy vehicle crashes are occupants of other vehicles. NSW data for 2008-2010 shows that 58% of fatalities in heavy truck crashes are occupants of other vehicles, 20% are occupants of the truck, 15% are pedestrians, 3% pedal cyclists and 4% motorcyclists (NSW Transport, 2011).

Crashes between the hours of 6pm and 6am represented 31% of fatal heavy vehicle crashes between 2002-2010, compared with 44% of crashes involving all vehicle types (Australian Road Deaths Database). Fatal articulated truck crashes were more likely to occur at night (38%) than rigid truck crashes (21%). While seasonal variation and geographic location influence the amount of daylight hours at particular times and places across Australia, it can generally be said that more than 70% of heavy vehicle crashes occur during daylight hours. A similar finding for fatal and serious injury crashes in Australia was reported nearly 20 years ago, a period when rigid trucks far outnumbered articulated trucks in both crash and registration data (Rechnitzer, 1993). In the more recent data (2002-2010), crashes involving articulated trucks are spread more evenly across the 24 hour period than those involving rigid trucks or buses (see Figure 2). As well as being greater in terms of the overall number of fatal crashes, with proportionally more crashes occurring at night, dusk and dawn, articulated truck crashes are arguably those most amenable to conspicuity treatments.

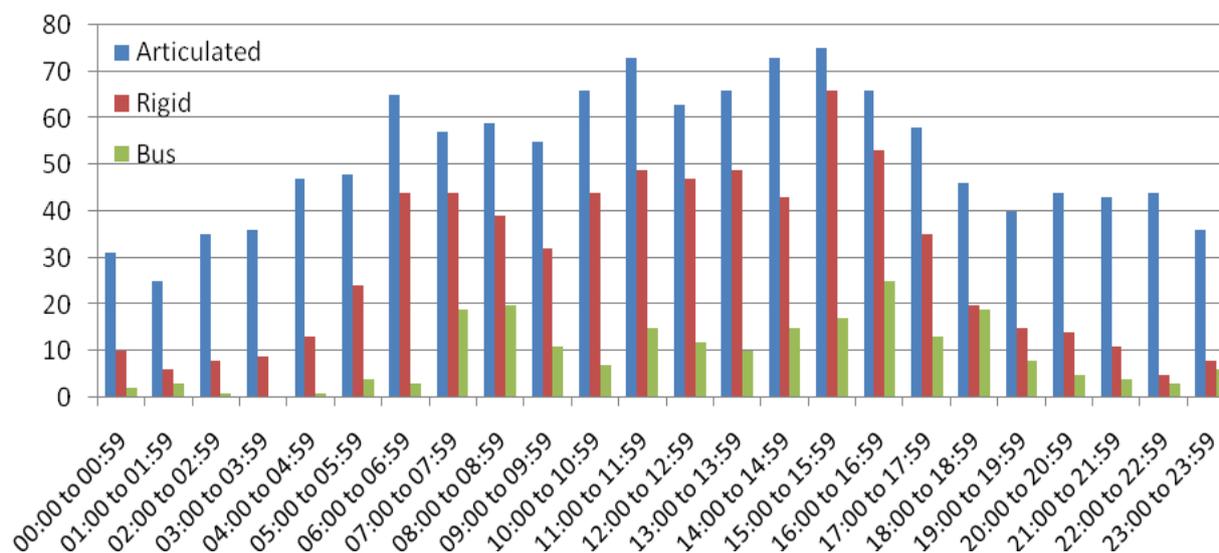


Figure 2: Fatal crashes involving heavy vehicle by time of day, Australia 2002-2010

A recent National Transport Insurance report (Driscoll, 2011) notes that truck crashes between the hours of 8pm and 6am have declined over the last decade, with a substantial reduction in fatigue-related crashes attributed partly to reforms around permissible driving hours (2008), as well as other unspecified factors. Poor conspicuity or visibility of heavy vehicles was not identified in the report as a contributing factor in crashes.

4. CURRENT REQUIREMENTS

Heavy vehicle conspicuity appears to be a problem that is mostly confined to hours of darkness and twilight according to the research literature. It is under such lighting conditions that a large proportion of crashes into the sides and rear ends of heavy vehicles occur, with (poor) conspicuity identified as a major contributing factor in some studies. For this reason, some countries have implemented mandatory contour marking and delineation of heavy vehicles using reflective materials, in addition to side and rear lighting fixtures. The addition of retroreflective contour marking has been found to reduce crash risk compared to vehicles fitted with side and rear lighting only, or no lights or reflective devices. The bulk of research on heavy vehicle conspicuity and contour markings, including several cost-benefit analyses, has mostly been conducted in Europe. The international research generally concludes that heavy vehicle conspicuity is a problem, and one that can be addressed through the application of contour markings. However, the findings of these studies are varied and their relevance for Australia needs to be investigated because of differences in a range of regulatory and environmental conditions between Australia and other countries.

4.1 Australia

The requirements related to the conspicuity of heavy vehicles in Australia are set out in the Australian Vehicle Standards Rules 1999 (Commonwealth of Australia, 1999), the Australian Design Rules (ADRs) (http://www.infrastructure.gov.au/roads/motor/design/adr_online.aspx) and the Australian Standards. Rear marking plates for heavy vehicles are mandated by Australian Vehicle Standards Rule 119, which calls up ADR 13/00 (Installation of Lighting and Light Signalling Devices on other than L-Group Vehicles) which in turn calls up Australian Standard AS4001.2: 2003 (Standards Australia, 2003).

Australian Vehicle Standards Rule 119 requires that a rear marking plate complying with rule 13.6.101 of ADR13 is fitted to a motor vehicle with GVM over 12 tonnes (except a bus fitted with handgrips for standing passengers) and any trailer with a GTM over 10 tonnes. The rule allows rear marking plates to be fitted to smaller vehicles.

Australian Standard AS4001.2: 2003 (Standards Australia, 2003) specifies that either Class 1 or Class 2 sheeting materials may be used as each comply with current requirements. However, this effectively means that two standards are operating simultaneously as Class 1 materials are a superior grade to Class 2. Although Class 1 and Class 2 materials each currently meet the requirements for vehicle markings under AS4001, only Class 1 materials are now used in most road signage applications as specified under AS1906 (King, 2010; Main Roads WA, 2011; WorkSafe, 2005). The superiority of Class 1 materials is therefore widely acknowledged, but its exclusive use is not currently mandated for vehicle conspicuity markings in Australia.

Figure 3 provides some examples of Class 1 rear marking plates and strips, adapted from WADPI (2004). The diagrams in Figure 3 show common applications of the marking plates and strips, though the dimensions and placement will vary according to the vehicle or trailer type and the amount and location of suitable surface areas. The specified colours are yellow retroreflective background, red transparent symbols and letters, and black letters.

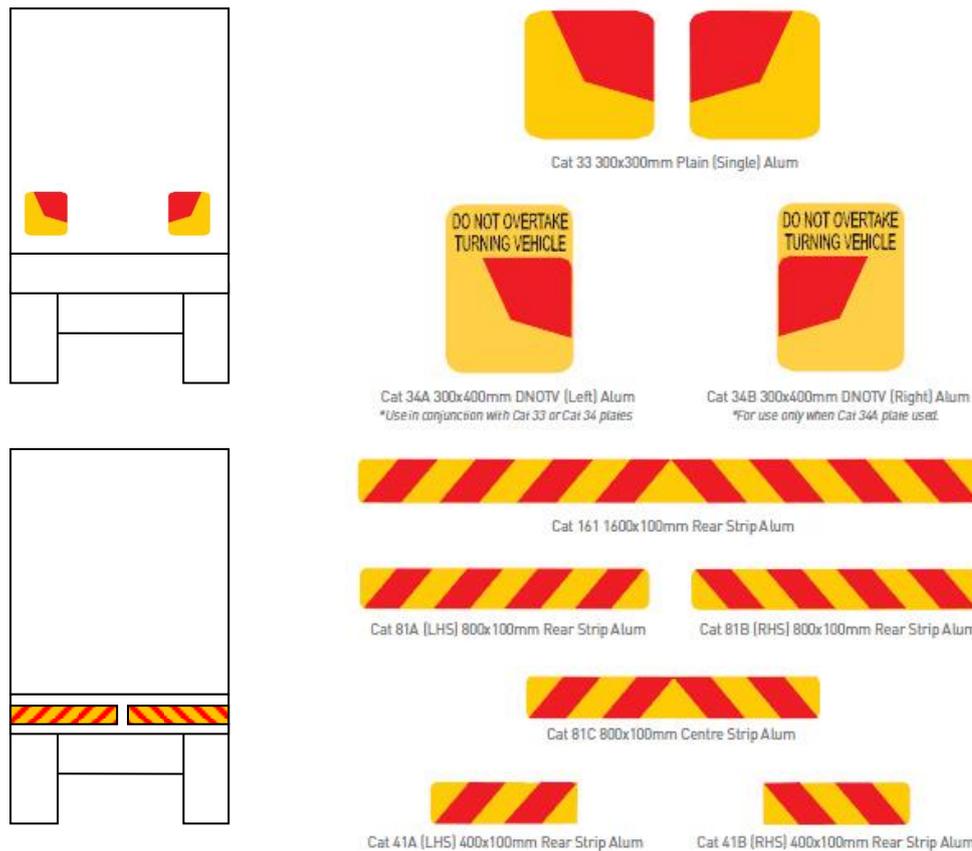


Figure 3: Australian Class 1 rear marking plate and strip examples, adapted from WADPI (2004).

Retroreflective side marking is not legally required and there is no relevant Australian Standard or regulation, although a voluntary code of practice based on European Regulation UN/ECE 104 was developed by the Australian Trucking Association in 2003 (King, 2010). There is similarly no requirement for fluorescent markings on heavy vehicles, but the potential of fluorescent material to complement the benefits of retroreflectivity when combined in marking sheets has been noted by the TUV Rheinland Group (2004) and King (2010).

There are a large number of other ADRs which relate to conspicuity, most of which relate to lighting devices. These include: ADR 1—Reversing Lamps; ADR 6—Direction Indicators; ADR 13—Installation of Lighting and Light-signalling Devices on other than L-Group Vehicles; ADR 47/00 – Retroreflectors; ADR 45—Lighting & Light-signalling Devices not covered by ECE Regulations; ADR 46—Headlamps; ADR 49—Front and Rear Position (Side) Lamps, Stop Lamps and End-outline Marker Lamps; ADR 50—Front Fog Lamps; ADR 51—Filament Lamps; ADR 52—Rear Fog Lamps; ADR 60—Centre High Mounted Stop Lamp; ADR 74—Side Marker Lamps; ADR 76—Daytime Running Lamps; ADR 77—Gas Discharge Headlamps and ADR 78—Gas Discharge Light Sources (http://www.infrastructure.gov.au/roads/motor/design/adr_online.aspx).

4.2 European Requirements and the UN/ECE104 Regulation

A detailed history of the European requirements is provided in GAK Oktató (2009). This section provides a general outline of the current situation.

UN/ECE Regulation 70 covers retroreflective rear marker plates which are required for vehicles with a gross vehicle mass exceeding 7.5 tonnes in European (EU) countries. This is similar to the current Australian requirement for rear marker plates, although the vehicle mass threshold for mandatory fitment is lower in Europe. Line and contour markings as specified under UN/ECE Regulation 48 (lighting and light-signalling devices) and Regulation 104 (retroreflective markings) were mandated from July 2011 and, where used, may either replace or complement rear marker plates.

Line and contour markings are essentially the same in terms of their purpose, materials and application. The fundamental difference is that line markings generally consist of a horizontal line that identifies vehicle length and width, while contour markings usually outline a surface profile (or 'contour'), identifying vehicle height as well as length and width. Contour markings thus indicate a greater surface area on enclosed truck and trailer bodies (potentially including tarpaulins and other soft or retractable coverings), but are redundant for flatbed trucks and trailers which can generally only accommodate line markings. Line markings are usually placed as low as practicable above the wheels, while contour markings ideally follow the outer contour of the entire vehicle above the wheels. There are variations on the precise configuration of contour and line markings across jurisdictions. For example, they may consist of continuous or broken lines and may be single or multicoloured.

Figures 4 and 5 illustrate the basic application of line and contour markings under the UN/ECE 104 Regulation for retroreflective markings⁶. Figure 6 shows a variation of contour marking in use in the UK (DfT, 2011), a configuration which would result in lower costs to the operator than full contour markings. The benefits in comparison to line marking and full contour marking are largely unknown, but they might reasonably be expected to lie somewhere between the two.

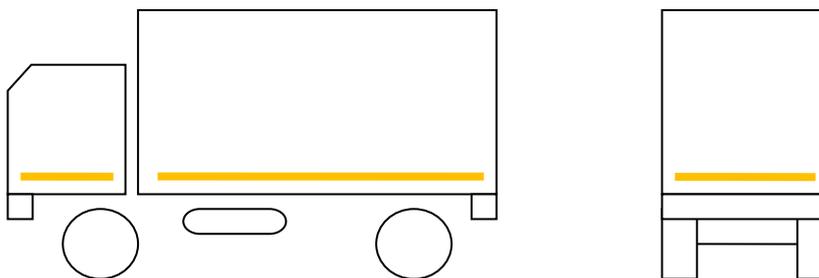


Figure 4: Side and rear line markings based on European ECE 104 application

⁶ In some cases continuous lines may be substituted with broken lines.

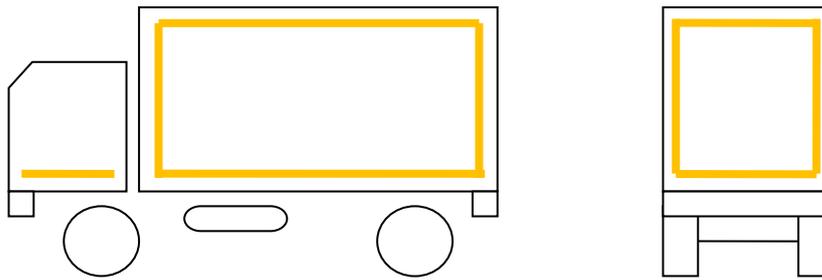


Figure 5: Side and rear contour markings based on European ECE 104 application

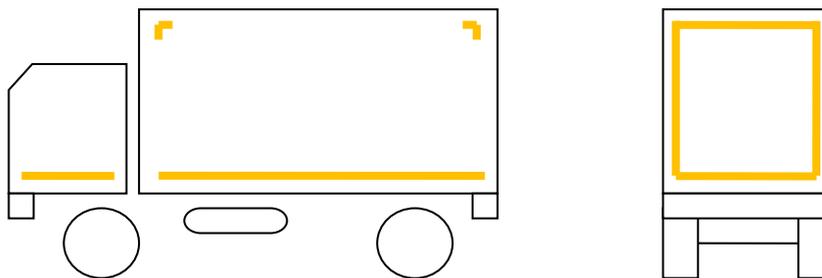


Figure 6: Side and rear contour markings based on UK (optional) requirements (FTA Compliance Guide) (DfT, 2011)

4.3 United States

In December 1992, the National Highway Traffic Safety Administration (NHTSA) amended Federal Motor Vehicle Safety Standard (FMVSS) No. 108, ‘Lamps, Reflective Devices, and Associated Equipment’, to require that all heavy trailers manufactured on or after December 1, 1993 must be equipped with red-and white retroreflective tape, sheeting and/or reflex reflectors around the sides and rear to make them more conspicuous (Morgan, 2001). Heavy trailers are at least 80 inches (203 cm) wide and have a Gross Vehicle Weight Rating over 10,000 pounds (4.54 tonnes). Retroreflective tape has been used almost exclusively for meeting the standard.

In March 1999, the Federal Highway Administration extended the application of this requirement to the entire on-road trailer fleet by directing motor carriers engaged in interstate commerce to retrofit heavy trailers manufactured before December 1993 with tape or reflectors. These older trailers were required to have some form of conspicuity treatment, by June 1, 2001, in the locations specified by the NHTSA standard for new trailers, except on the rear impact guard. This Federal Motor Carrier Safety Regulation gave motor carriers until June 1, 2009 to retire their pre-1993 trailers or retrofit them with treatments that conform exactly to the NHTSA standard (again, with the exception of the rear impact guard).

5. FINDINGS REGARDING CONSPICUITY TREATMENTS

Many studies have been conducted into the effects of vehicle conspicuity on road safety, ranging from bicycles to motorcycles to cars to locomotives and rolling stock. The studies reviewed here are confined to those expressly focusing on heavy vehicles. Four types of research are summarised here: descriptions of the cognitive and perceptual factors affecting visibility, examinations of the effects of vehicle markings on driver reaction times and judgements of speed and distance, studies of the effects of vehicle markings on crashes and analyses of cost-benefit ratios for mandatory application of vehicle markings.

5.1 Cognitive and perceptual factors affecting visibility

It has been noted that visual perception is limited in poor lighting conditions, and that in such situations heavy vehicles may move relatively slowly, thus presenting a particular problem for other road users. According to Schmidt-Clausen (2000) the particular problem arises from the increased cognitive demands upon drivers of scanning for, perceiving and responding to hazards in poor light, and the vulnerability of other road users in heavy vehicle collisions (high fatality rates).

Drivers following and/or approaching other vehicles head-on have been noted to have poor judgement of the relative speed (or velocity) of the vehicle ahead, causing them to often misjudge their closing speed (Lawton, Richardson, & Welsh, 2005). This perceptual limitation has been offered to explain the relatively frequent occurrence of rear end crashes and is something that rear contour marking has the potential to address (Hoffmann & Mortimer, 1996; Messerschmidt, 2011). While lights, conventional reflectors and marking plates are effective for basic identification, contour markings provide a larger and better defined pattern which may be more readily perceived as approaching (or vanishing) in the distance (Messerschmidt, 2011).

Some of the literature suggests that conspicuity markings should not only alert approaching to the presence of an obstacle, but that the obstacle should also be recognisable (Dutch Transport Safety Board, 2003). This view is supported by Lawton, Richardson et al. (2005), noting that identification of a vehicle type will assist observers to better predict its likely motion. The studies referred to in this section have mostly concerned rear-end crashes, but Lawton, Richardson et al. (2005, p.7) also address side impact crashes:

Generally speaking, in terms of the failure of the driver's visual processing, collisions with the rear of large vehicles can be a result of a failing in any one of the 'see', 'recognise' and 'interpret' stages. Collisions with the sides of such vehicles, especially where they have arisen from the large vehicle being effectively stationary across the path of the following vehicle, most probably arise from a failure of the first two stages.

5.2 Effects of conspicuity on reaction time, and judgement of speed and distance

A range of studies have concluded that the distance from which a truck or other vehicle can be detected in poor light is increased considerably with the application of retroreflective contour markings, with the general outcome being fewer crashes involving heavy vehicles

and other road users in poor lighting conditions (de Niet, Goldenbeld, & Langeveld, 2002; Dutch Transport Safety Board, 2003; IRF, 2002; Lawton, et al., 2005; LBI, No date; Messerschmidt, 2011; Morgan, 2001; Richardson & Lawton, 2005; Schmidt-Clausen, 2000; Sullivan & Flannagan, 2004; TUV Rheinland Group, 2004). Reporting on a series of large-scale and laboratory experiments, Schmidt-Clausen (2000) claims that up to 97% of relevant crashes (involving trucks and cars in poor visibility) could be avoided through the use of retroreflective conspicuity markings. While questioning the reliability of this estimate and suggesting more moderate crash reductions were likely, others have generally agreed on the efficacy of the measure (Dutch Transport Safety Board, 2003).

The TUV Rheinland Group (2004) concluded that contour markings can reduce approaching drivers' reaction times by a factor of more than five. Recognition distances are claimed to increase by 50% to >500%, and in adverse weather conditions contour markings are claimed to outperform signal lamps. Schmidt-Clausen (2000) also referred to reaction times and was in general agreement with the TUV Rheinland Group (2004), though was more specific, claiming that reaction times for side and rear contour markings were between 0.4 and 0.6 seconds, compared with more than 5 seconds for single reflectors. Criticisms of single reflectors included that they are often small, poorly positioned and more prone to becoming dirty (and thus ineffective) than line or contour markings (Schmidt-Clausen, 2000).

Other research has produced more moderate though still significant results. Comparing reaction times for approaching the rear of trucks, the Ludwig Boltzmann Institute (LBI, 2001) reported that marked trucks were detected at a distance of about 420 metres on average, compared with unmarked trucks at about 195 metres. Similar results were found for approaching the side of trucks at right angles, with marked vehicles detected at 579 metres compared with unmarked vehicles at 363 metres.

5.3 Effects on heavy vehicle crashes

Few studies were identified that specifically evaluated the effects of reflective markings on heavy vehicles on actual truck crashes. Many studies applied effectiveness estimates derived from experimental studies of truck visibility to crash data without detailed information about the actual vehicles in crashes (e.g. Schmidt-Clausen, 2000).

In the early 1980s the British Motor Industry Research Association (MIRA) undertook a two year study of commercial vehicle accidents (cited in Richardson & Lawton, 2005). Of the 200 accidents recorded and analysed, 26 were considered to be conspicuity related; defined as those accidents which 'might have been lessened in severity or eliminated altogether had another road user seen the commercial vehicle earlier'. Of these 26 accidents, half (equivalent to 6.5% of the total sample) occurred in conditions of poor visibility (twilight or night) where retroreflective markings might have helped to reduce crash and injury risk. Additionally, some of the crashes that occurred in daylight hours may have been prevented through fluorescent conspicuity markings.

As part of the development of the US requirements for heavy vehicle markings, NHTSA commissioned a fleet study to evaluate the crash reduction effectiveness of applying reflective tape to the sides and rears of commercial trailers over a 23-month period in 1983-1985 (Burger et al., 1985 cited in Morgan, 2001). Of the 3,820 van trailers selected for participation, half were treated with retroreflective tape; the other half served as a control group against which the performance of the treated trailers was compared. The markings

comprised alternately hatched red and white or blue and white, two-inch wide strips of retroreflective tape to outline the lower side rail on both sides of the trailer and the rear perimeter of the trailer. Each of the two groups accumulated 106 million miles of exposure during the study period. The tractor-trailer combinations in the treated fleet were struck by other vehicles 15 percent fewer times than were combinations in the control fleet; the report did not distinguish side from rear impacts. From its final review of the field test analyses, NHTSA estimated that use of the material would reduce crashes into the side and rear of combination trucks in dark conditions by 15 percent and 25 percent, respectively. They also estimated that injuries and fatalities in these crashes would be reduced by 15 percent.

Morgan (2001) reported a study of crashes into heavy trailers investigated by the Florida Highway Patrol and the Pennsylvania State Police in 1997-1999. It analysed tractor-trailer crashes according to: (1) whether or not the trailer is tape-equipped; (2) the light condition – ‘dark’ (comprising ‘dark-not-lighted’, ‘dark-lighted’, ‘dawn’ and ‘dusk’) vs. daylight; and (3) relevant (another vehicle crashed into the side or rear of a heavy trailer) vs. control-group (single-vehicle crashes of tractor-trailers and impacts of the front of the tractor into other vehicles). She concluded that retroreflective tape ‘reduced side and rear impacts into trailers, in dark conditions by 29 percent’ (p. ii). In ‘dark-not-lighted’ conditions, the tape reduced side and rear impact crashes by 41 percent. Tape is especially effective in reducing injury crashes. In dark conditions, it reduced side and rear impacts that resulted in fatalities or injuries to drivers of any vehicle by 44 percent’ (from Technical Report Documentation Page). In dark-lighted, dawn, and dusk conditions, the tape did not significantly reduce crashes. The tape also did not significantly reduce crashes during daylight. While the report does not refer to fluorescence as a property of tape used on trucks in the study, tape applied in the mid-1990s is of generally lower quality to that used today (such as Class 1 as described) and is likely to have been non-fluorescent. Morgan notes that the tape is effective in both clear (28 percent) and rainy/foggy weather conditions (31 percent). The tape is especially effective on flatbed trailers (55 percent). These low-profile vehicles must have been especially difficult to see in the dark before they were treated with tape. Dirt on the tape significantly diminished its effectiveness in rear impacts. Clean tape reduces rear impacts by 53 percent but dirty tape by only 27 percent.

The TUV-Rheinland (2004) report cites a 2001 study by Assing of an extensive accident analysis for trucks of a gross weight >12 tonne. For the relevant conspicuity crashes it reported a maximal possible avoidance of 12% to 29% on motorway crashes and of 1-4% of main road crashes. It noted that the amount of side impacts on main roads is double that of rear impacts on main roads. An 8.9% overall maximal possible reduction of fatalities through the use of markings over the time period 1995 – 2001 was calculated. Detailed specifications of the material are not reported but the markings used during the study period are likely to be of lower quality than those currently available. The TUV-Rheinland report also cites a 1998 study by Cook which found that 2% of crashes could be prevented by passive markings, though these findings are noted as conservative and potentially unreliable.

A report prepared for the European Commission (TUV Rheinland Group, 2004) presented a range of cost-benefit ratios likely to result from mandatory retroreflective contour markings on HGVs (heavy goods vehicles) under various regulatory and other conditions. To identify crashes which may have potentially been avoided through the use contour markings, the study selected crashes from the CARE database of fatal and injury crashes in 15 EU member states. Crashes selected met conditions of having occurred at night, dawn or dusk, involving a HGV >3.5 tonnes gross weight, impacted at side or rear by another vehicle, in the absence of

street lighting, and where a recognition problem (too late or none at all) was a stated crash cause. The proportion of relevant crashes (in darkness or twilight, side or rear impact at the HGV) where ‘recognition too late’ and ‘no recognition at all’ were the causes of crashes varied from 44% on motorways and outside urban areas to 22% inside urban areas.

Schmidt-Clausen’s estimate of an effectiveness of 95% for the relevant crashes was then applied to determine how many accidents, fatalities and personal injuries could be avoided. Then the number of property damage crashes that could be avoided was estimated. The report claimed a relevant crash avoidance potential of between 2% and 41%.

Full contour markings have been shown to be more effective than line markings, although the extent of this difference is unclear (Lawton et al., 2005). There are numerous variations of the standard configurations, including broken lines, dotted lines and partial contours, as well the use of different colours and different grades of material which may impact the distance and angle from which the markers are visible.

5.4 Cost-benefit analyses

Four published cost-benefit analyses of the effects of mandatory retroreflective markings on heavy vehicles were found. Their characteristics are summarised in Table 2 below.

Table 2. Summary of cost-benefit analyses of the effects of mandatory retroreflective markings on heavy vehicles.

Study authors, date	Country	Type of marking	Type of vehicle	BCR
Federal Highways Administration, 1999	USA	Not stated	Articulated trucks, retrofit	1.58 over 10 years
Dutch Institute for Road Safety Research, 2002	The Netherlands	Contour	Not stated	‘not much greater than 1’
TUV-Rheinland Group, 2004	European Commission	Contour	HGVs >3.5t, new vehicles	1.2-3.6 for HGVs>3.5t, 1.4-4.0 for HGVs>12t
Lawton et al., 2005	Great Britain	Line, contour	Various	Greater for line marking, greater for heavier vehicles

A cost-benefit analysis of conspicuity retrofits for the rear and sides of trailers (articulated trucks) was also published by the U.S. Federal Highways Administration (FHWA, 1999). The estimated cost ‘per fatality and equivalent fatality avoided is just under \$1.5 million’ (US\$).

Estimated material and application costs ranged from US\$126 to US\$174 per vehicle (trailer), depending on trailer length. Added to these costs were opportunity costs of approximately US\$140 per trailer, comprising about 45% of average total costs per trailer. Over 10 years the regulation was expected to realise a ('conservatively estimated') 15% reduction in crashes into the side or rear of trailers, 102 fewer fatalities, and a cost-benefit ratio of 1.58.

A report on retroreflective contour marking by the Dutch Institute for Road Safety Research (SWOV) found that cost-benefit ratios were positive overall, yet the calculated benefits were only marginal (de Niet, et al., 2002). This report was commissioned by 3M Netherlands to determine the safety effects of and opportunities for introduction of retro-reflective contour marking on freight cars in the Netherlands (a rough auto-translation of the forward in the report). The main body of this report is printed in Dutch, but the following conclusions are offered in the Executive Summary:

The estimated benefit-cost ratio is to be regarded as modest; not much greater than 1, which is the critical value for a socially profitable measure. The cost effectiveness, in comparison with other potential measures, is rather low. At the investment level, seeing the cost-benefit ratio found, the measure is not profitable.

A report prepared for the European Commission (TUV Rheinland Group, 2004) presented a range of cost-benefit ratios likely to result from mandatory retroreflective contour markings on HGVs (heavy goods vehicles) under various regulatory and other conditions. The authors also note that 'there is no sufficiently precise cost-benefit analysis available for Europe' (TUV Rheinland Group, 2004, p. 1). In these analyses, the monetary cost of one road user fatality was conservatively valued at €1 million, while the average estimated cost (excluding taxes) for contour marking HGVs larger (heavier) than 3.5t was €408 per vehicle (approximately 60% material and 40% application, 2004), possibly reducing to €233 in the event of Europe-wide regulation (an economy of scale effect reducing the cost of materials). Based on a program in which only new or newly registered vehicles were required to be fitted, full benefits in terms of crash reduction were estimated to be realised in 12-15 years. Current cost-benefit ratios for HGVs over 3.5t were calculated at between 1.2 and 3.6, and slightly higher for HGVs over 12 tonne (1.4 – 4.0). This report does not appear to factor in opportunity costs in relation to removing the vehicle from service for application of the conspicuity markings. However, these costs could be minimised by having the markings applied while the vehicle is out of service for scheduled maintenance.

A report prepared for the Department of Transport in Great Britain (Lawton, et al., 2005) notes difficulties in obtaining useful (accurate) data, as well as problems with comparing situations between countries. For example, 'categories used to classify vehicle type in the U.K national accident database (STATS 19) use different vehicle weight boundaries to comparable European databases' (p. 4-5). The report also makes the following key points in its Executive Summary:

• The costs of fitting tape to new vehicles is considerably lower than the costs incurred when retro fitting tape to vehicles. This is due to the reduced time taken to fit the tape and that no off road costs are incurred. It should also be noted that as the years progress the proportion of the total vehicle parc fitted with retro reflective tape will also increase and therefore this will increase the number of

accidents prevented. However it should also be noted that after 7 years the costs will also increase due to the need to start replacing tape on the earlier marked vehicles and this will incur the higher costs associated with of retro fitting.

- There is a cost benefit for fitting line markings to newly registered HGVs greater than 7.5t, minibuses and coaches/buses.*
- Fitting line markings to newly registered vehicles over an 8 year period shows that a benefit arises for >7.5 (tonne), minibuses and coaches/ buses with benefits occurring after the 3rd and 4th years respectively.*
- A benefit for fitting contour markings to new HGVs >7.5t occurs in the 5th year.*

Some cost-benefit analyses assume a one-off cost for fitting HGVs with contour or line markings in a period of 10 or more years (TUV Rheinland Group, 2004), but the average lifespan of current retroreflective materials is about seven years according to Lawton et al. (2005). Two particular products in 3M's Diamond Grade Vehicle Marking Film Series, 'can be used for 3 and 8 years respectively' (GAK Oktató, 2009), illustrating considerable variation in product performance and deterioration over time. It seems reasonable to expect that lifespan would have some influence on price.

6. RELEVANCE OF INTERNATIONAL RESEARCH FOR AUSTRALIA

As mentioned earlier, there are numerous environmental and regulatory differences between Australia and other countries which limit the transferability of international research findings to Australia. Relevant to heavy vehicle conspicuity, these differences include:

- Hours of daylight and length of day-night transition period (twilight)
- Atmospheric conditions (rain, snow, fog etc.)
- Regulations on headlight use (e.g. daytime running lights)
- Regulations on heavy vehicle specifications
- Amount of night driving by heavy vehicle drivers and other road users
- Crash characteristics

6.1 Hours of daylight

As latitude increases, the duration of the day-night transition period (twilight) increases and there are fewer hours of daylight in winter. Most of the highly travelled area of Australia lies between 15 and 40 degrees south. In contrast, most of the highly populated areas of the US fall between 30 and 45 degrees north, Canada between 45 and 55 degrees north and Europe 40 and 65 degrees north (Italy 37-47 degrees north, Germany 47-55 degrees north, Netherlands 52-53 degrees north and UK 50-58 degrees north). This means that Australia is relatively closer to the equator and so has less twilight and more hours of daylight in winter (and thus relatively less benefit from retroreflective markings) than other countries. The observation by Schmidt-Clausen (2000) that about 40% of crashes in EU countries occur at night, dawn or dusk is thus not necessarily reflected in Australia, where the proportion of crashes occurring at these times may be generally lower (on the other hand there may be proportionally more or less night driving in Australia).

As noted in Section 3.1, crashes between 6pm and 6am comprised 31% of fatal heavy vehicle crashes in Australia from 2002-2010. On the other hand, an earlier report by Haworth and Vulcan (2002), showed a higher proportion of fatal truck crashes occurring at night (39%), suggesting changes in the amount of night driving over the last decade or more, consistent with Driscoll (2011). However, with driving hours less constrained and with longer travel distances relative to Europe, it is possible that the amount of night driving in Australia may increase in future and, therefore, the number of night time crashes.

Spanning a large distance from north to south, there is also a notable difference between Australia's northernmost and southernmost capital cities in the amount of daylight on any given day. In the south, Hobart receives 15 hours and 21 minutes sunlight on its longest day (21 December in 2012) and 9 hours and 1 minute on its shortest day (21 June in 2012). In comparison, on these same days Darwin receives 12 hours and 52 minutes, and 11 hours and 24 minutes respectively. This makes it difficult to accurately separate daytime from night-time crashes across Australia using consistent time periods.

6.2 Atmospheric conditions

There is relatively little published research that bears on the issue of whether adverse atmospheric conditions are more or less important for heavy vehicle crashes in Australia compared to the rest of the world. While snow is certainly less common in Australian driving

conditions than in North America and Europe, the relative likelihood of rain is not known. Fog is probably less common in Australia than in Europe, but may certainly influence safety in some parts of the country during cooler months. While any of these atmospheric conditions can severely restrict visibility, rain is likely to be more prevalent than fog or snow in Australia. Research in the US (Morgan, 2001) has shown that retroreflective tape was equally effective under these conditions as in clear conditions, although the tape in question was red and white rather than red and yellow as used in Australia, so may have had a different effect.

6.3 Regulations on headlight use

Daytime use of headlights or daytime running lights is required in many jurisdictions but not in Australia. In low light conditions during daytime, where headlight use is generally discretionary in Australia, retroreflective markings may be more effective when headlights are in use. An increasing number of new vehicles are supplied with sensors that activate headlights automatically in low light conditions, often referred to as ‘dusk sensors’. This is a feature which is likely to help maintain the effectiveness of retroreflective markings in poor light during daytime, but is not currently required under Australian Design Rules and is not standard fitment for all new vehicles in Australia. Further, such technology was not included in a recent report on vehicle safety attributes in South Australia (Anderson, 2012), suggesting that the safety benefits may be minimal. The top selling new car in the first half of 2011 in Australia (Beissmann, 2011), the Mazda 3, was not available with an automatic lights-on function according to manufacturer’s specifications:

<http://www.mazda.com.au/vehicles/mazda3/specifications>. Of four other model ranges in the top 10 selling cars, one (Holden Commodore) had an automatic lights-on function as standard for all models, while three other cars (Toyota Corolla, Mitsubishi Lancer and Volkswagen Golf) supplied dusk sensors on higher end models but not on base models. It is likely that such technology will become more prevalent in the new car market and eventually filter through in used car sales over time. Additionally, the fluorescent material in Class 1 retroreflective sheeting can partly counter this potential problem as it does not rely on an artificial light source to be highly visible during daytime.

6.4 Regulations on heavy vehicle specifications

The absence of comprehensive mandatory requirements for rear and side under-run protection for heavy vehicles in Australia contributes to an increased severity of crash outcome (Rechnitzer, 1993). As noted previously, daytime running lights are also not required in Australia. In the absence of such requirements, it could be argued that it is even more important to improve heavy vehicle conspicuity in order to prevent or ameliorate the impact of under-run crashes involving trucks.

6.5 Crash characteristics

The *Truck safety benchmarking study* (Haworth & Vulcan, 2002) identified a number of ways in which the characteristics of truck crashes vary between Australia and other countries. Those which could potentially **increase** the benefits of conspicuity markings for heavy vehicles are the following:

The percentage of crashes at night is higher for Australia (39%) than in France (29%), New Zealand (28%) and Great Britain (18%).

The percentage of crashes which occur in speed zones of 100 km/h or greater is 58%, in Australia and 70% in New Zealand, but only 24% in Canada.

Those which could potentially **decrease** the benefits of conspicuity markings for heavy vehicles are the following:

The percentage of single vehicle crashes (including pedestrians) is higher for Australia (25%) than for the other countries (14% to 20%).

The percentage of crashes in urban areas in Australia (42%) is higher than that in Canada (29%), New Zealand (28%), Germany (25%) and Sweden (21%)(Haworth & Vulcan, 2002).

The Haworth and Vulcan (2002) report does not specifically mention heavy vehicle conspicuity or visibility, either as a contributing factor in crashes or as a potential area for intervention. However, crashes into the rear and sides of heavy vehicles are identified as a problem that could be addressed by improving underrun protection on trucks and trailers. Such measures aim to reduce the severity of these types of crashes, but are not intended or likely to prevent their occurrence. By contrast, contour markings and other conspicuity treatments do aim specifically to reduce the occurrence of such crashes, particularly in poor lighting conditions, with crash prevention clearly preferable to ameliorating severity outcomes. In the event that contour markings fail to prevent such incidents altogether, they may also reduce crash severity by allowing approaching vehicle drivers to detect the hazard sooner and thereby reduce their speed prior to impact.

Fatality rates per distance travelled and per registered vehicle have been found to be higher for articulated trucks than rigid trucks in Australia (Haworth & Symmons, 2003). Consistent with this, articulated truck crashes were found to be more severe overall than those involving rigid trucks. The distance travelled annually by freight vehicles increased by 20% in Australia in the five years to October 2007, with the greatest increase among articulated trucks (24%). On average, rigid trucks travelled 24,000 km annually, while articulated trucks travelled almost four times as far (98,000 km) (ABS, 2008).

It is possible that markings are more likely to get dirty in Australia compared to other countries because of more heavy vehicle travel on unsealed roads or narrow pavement widths such that at least some wheels are in the dirt.

There are currently no analyses of Australian crash data that identify heavy vehicle crashes which may have been prevented or which may have been less severe if the truck involved had contour or line markings applied. Such analyses are essential for performing a reliable cost-benefit analysis, but as noted in the literature the necessary data are difficult to obtain.

7. ASSESSING POTENTIAL BENEFIT:COST RATIOS UNDER AUSTRALIAN CONDITIONS

In order to assess the potential benefits of mandating retroreflective marking in Australia, it would be useful to have clear answers to the following questions:

- *What is the likely probability of a truck being involved in a multi-vehicle crash per year in Australia versus other jurisdictions?*

Blower and Woodrooffe (2012) note similarities between Australia and the US, where trucks comprise comparable proportions of vehicles in use (about 3-4%), with a similar split of rigid and articulated trucks. Fatal truck crashes mostly involve articulated trucks in both countries (although rigid trucks are far more numerous), and about 85% are multi-vehicle crashes, but the proportion of all fatal crashes which involve trucks is higher in Australia (15%) than in the US (8.3%). Conversely, fatality rates in truck crashes are higher in the US per 10,000 truck registrations (6.7 versus 4.3) and per 100,000 population (1.7 versus 0.9). It is thus possible to coarsely compare crash rates, but the results can be somewhat misleading. Differences between jurisdictions in terms of truck specifications and design, usage regulations, data availability and various other factors render comparing crash risk for heavy vehicles across countries a complex undertaking beyond the scope of the current report.

- *Are the costs of fitting used in other studies relevant to Australia?*

The costs of fitting used in cost-benefit analyses from other countries may be generally relevant to Australia, notwithstanding fluctuations in economic performance and international exchange rates. However, there are many variables which need to be considered to accurately determine comparative costs of fitting the vehicles, including the mix of surface types (soft/hard etc), the value of vehicle downtime and the labour costs involved (TUV Rheinland Group, 2004). An additional question concerns whether or not the earlier cost-benefit analyses used values that are still relevant given changes over time.

- *Is the likely mix of new and existing vehicles the same in Australia as in other countries?*

This will be an important consideration in cost-benefit analyses as the cost of fitting new vehicles will differ from that of retro-fitting the existing vehicle fleet. The timeframe for retro-fitting existing vehicles is also an important consideration, as is the expected lifespan of the materials (which may be shorter for materials applied to soft covers).

- *How should the additional benefit of improved daytime conspicuity due to the fluorescent nature of the materials be estimated? This does not appear to be included in earlier studies.*
- *What percentage of heavy vehicles in Australia currently have the treatment without the mandatory requirement?*

While there are no official data available, 3M have estimated that less than 5% of heavy vehicles in Australia currently have retroreflective line or contour markings, based on product sales of 3M and its competitors (pers. comm., Berces, May 2012). In light of their demonstrated effectiveness, this suggests considerable potential for conspicuity markings to generate crash reductions, though a rigorous cost-benefit analysis for Australia using accurate data remains desirable.

7.1 Factors affecting the likely costs and benefits of mandation

The likely costs and benefits of mandatory conspicuity markings for heavy vehicles in Australia (beyond the current requirements for rear marking plates) will depend on many factors. These include:

- whether the requirement is for line markings, full contour markings, or some variation of these (such as illustrated in Figure 6 for the UK, for example)
- the vehicle specifications (mass, length etc) to which the requirement/s would apply
- whether the requirement would apply to all vehicles of certain specification, or only new vehicles
- the timeframe for implementation
- the cost, grade and lifespan of materials
- opportunity costs for operators
- the value of each crash and equivalent crash cost avoided

Other considerations for estimating and evaluating the likely costs and benefits:

- What data exist for evaluation in Australia, and what data are required?
- Future evaluations will need to control for other coinciding road safety countermeasures, including in-car collision avoidance systems, for example.
- Retro-fitting of trucks and trailers with contour marking is likely to be inexpensive for operators, although more expensive than fitting for new vehicles.
- What level of enforcement should/would be applied after full implementation, and will it be consistent across jurisdictions (assuming a national regulation is applied)? Low compliance has been seen in some other countries where mandated, such as South Africa (Haarhoff, 2004). However, there are opportunities to monitor compliance state-wide or nationally, for example at the time of registration renewal as is the case in Europe, to achieve close to full compliance.

8. CONCLUSIONS

Crashes involving heavy vehicles and other road users are still a significant issue in Australia, with approximately 240 fatal truck crashes occurring annually over the last decade. The fatal crash rate per 100 million VKT for articulated trucks (1.8) is about double that for rigid trucks (0.9) from 2002-2010. Approximately 31% of fatal heavy vehicle crashes in Australia occur at night, with articulated trucks more likely to be involved in fatal night crashes than rigid trucks (38% vs. 21%). Research from other countries shows potential crash reductions of relevant crash types of approximately 2% to 45% from the use of conspicuity markings, and estimated cost-benefit ratios have been generally positive.

The relatively high percentage of fatal articulated truck crashes occurring at night in Australia suggests that improved conspicuity markings may have a significant effect in reducing crashes. Higher grade (Class 1) retroreflective materials which combine fluorescence with reflective properties in conspicuity markings may also help to reduce daytime heavy vehicle crashes. Materials that retain some effectiveness when dirty would appear to be most suitable for Australian conditions. There is a need for more research on the potential effectiveness of improved conspicuity markings for heavy vehicles in Australia, particularly with regard to cost-benefit ratios and the many variables to consider in such calculations. However, the available evidence suggests that a significant reduction in conspicuity-related crashes is possible with appropriate application of high quality conspicuity markings.

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