IMPROVING ROAD SAFETY
BY INCREASED TRUCK VISIBILITY

Author:
Agota Berces,
Technical, Regulatory and Business Development Manager
3M Traffic Safety Systems Division, NSW
Phone: 02 9498 9460, Fax: 02 9498 9612
E-mail: agota.berces@mmm.com

Introduction

Road safety is gaining an ever increasing focus by the Australian public and governments at all levels. They are looking at reducing our road tolls through a range of road safety initiatives. This growing attention on road safety over many years has seen a decrease in accident rates but still more can be done to incrementally improve these results. Many of these initiatives are high cost and long term and will take many years to implement, but many of the low cost, immediate impact measures are often ignored.

This paper focuses on heavy vehicle safety and aims to demonstrate how innovative reflective technologies can prevent truck crashes and fatalities by increasing their visibility. Over the last 10 years the road toll has shown a declining trend in all vehicle categories, including heavy vehicles despite the facts that the number of vehicles and the kilometres travelled on the roads have significantly increased. It is important that the downward trend remains and simple, low cost conspicuity measures support and accelerate the declining tendency.

The problem

All transport experts agree in stating that the mobility of people and goods affects our growth and well-being, making it one of the major socio-economic challenges of the year's 2000 plus. (Schmidt-Clausen 2000)

To understand the road death problem related to heavy vehicles, the latest statistical data from various sources across the country are presented by Figures 1-4. The same data will be used later in the paper for hypothetical calculations of saving lives with improved visibility. Figure 1 shows the data from October 2009 to September 2010, a cumulative one year period. During these 12 months 1392 people died on our roads and out of these 1392, 250 fatalities are related to heavy vehicle accidents. It is evident that heavy vehicle crashes contribute to overall road fatalities significantly in Australia as 18% of all road crashes involve these types of vehicles.

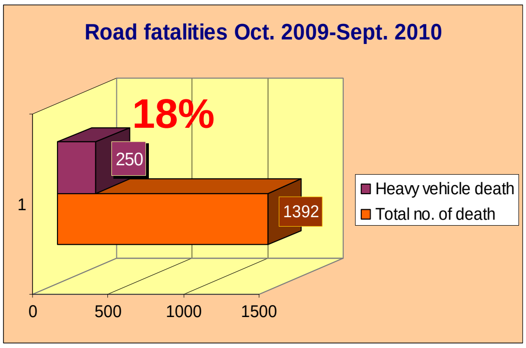


Figure 1 – Road death in Australia vs.heavy vehicle fatalities

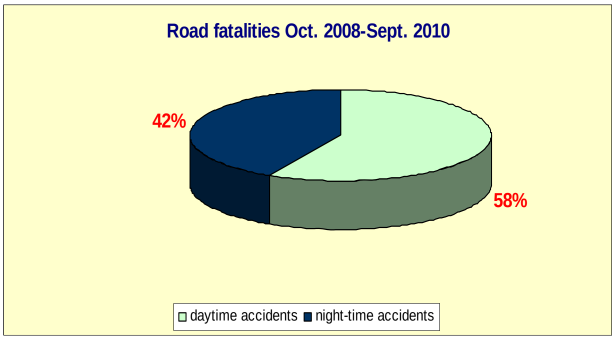


Figure 2 – Road death in Australia by time of the day

As our aim is to explore the benefits of improved visibility, it is important to investigate when accidents occur. According to the data available for a 2 year period of 2008-2010, accidents during night-time represent 42.1% of the total number of road death; hence decreased visibility might play a significant role why crashes happen. (Figure 2) Taking serious and light injury accidents also into account, a study done by the Monash University Accident Research Centre concluded that crashes that occur during the night are more severe than the ones during daytime. (Haworth and Symmons 2003)

Statistics show that 18% of all road fatalities involve heavy vehicles and about 42% of crashes happen during night-time, so we can calculate that 105 fatalities occurred in the 12 months period of 2009-2010 where heavy vehicles were affected in dark conditions. (Figure 3) These 105 fatalities represent both single and multiple vehicle crashes. In terms of single vehicle accidents fatigue was found to be the major cause which resulted in the driver running off the road. Fatigue influenced accidents are out of the scope of this analysis.

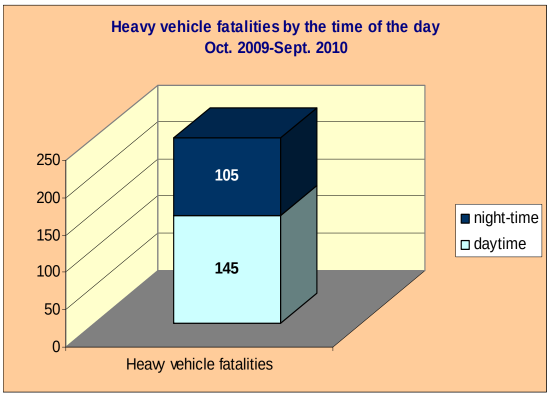


Figure 3 – Heavy vehicle fatalities by the time of the day

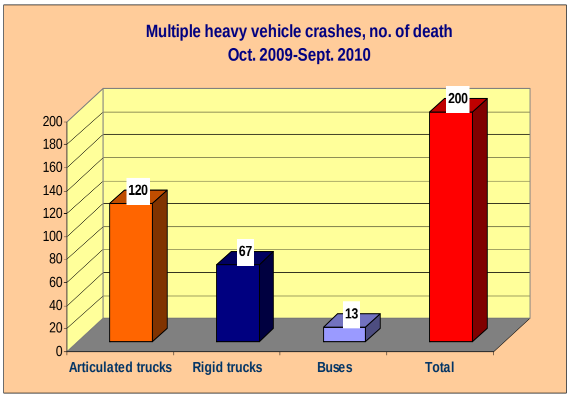


Figure 4 – Multiple vehicle crashes involving heavy vehicles Number. of death

Further breaking down the numbers and narrowing the analysis to multiple vehicle crashes only, involving articulated trucks, rigid trucks, buses and other road users, we can conclude that altogether 200 people lost their lives between October 2009 and September 2010. (Figure 4) Assuming that 42% of the accidents happen during limited visibility conditions, we can calculate that 84 people died in night-time accidents within a 12 month period involving heavy rigid trucks, articulated trucks and buses.

As visibility conditions could also play a significant role in these accidents, improving heavy vehicle visibility would focus on the annual saving of these 84 lives, as conspicuity requirements could help to reduce and prevent the number of collisions.

Looking at the European situation, crash investigations show that approximately 5% of severe truck accidents can be traced back to poor recognition of the truck or its trailer, mostly at night (ETSC 2006). The European Commission has popularised the one million Euro principles, which states that “a road safety measure which saves at least one life in road traffic at a cost of up to 1 million Euros is justified on economic grounds alone (not taking into account the human suffering)”. (IRF 2004)

Another aspect of multiple vehicle crashes involving heavy vehicles to be noted is that 74% of these types of collisions happened in the 90 or higher speed zones in the past five years, 2005-2010. (Bitre 2010) The larger the travelling speed is, the longer detection distance is required to detect, recognise and manoeuvre away safely to avoid the collision as illustrated by Figure 5. For example if a vehicle is moving at 80 km/h, it requires 56 metres to stop whereas if it is travelling at 110 km/h, the distance to be able to bring the vehicle to a halt is 100 metres. Let’s imagine this scenario: we are driving at a speed of 110 km/h at night, in dry weather conditions, on a straight section of a rural road without any street lights or other light sources. The only light source we have is our own car headlamp. A truck is approaching the intersection turning onto the main road where we are driving. In this case if we detect the other vehicle from a 100 metre distance, it is already too late to push the brakes. The average safety distance would require at least 220 metres as stated by the LBI Unfallforschung (2001) study.

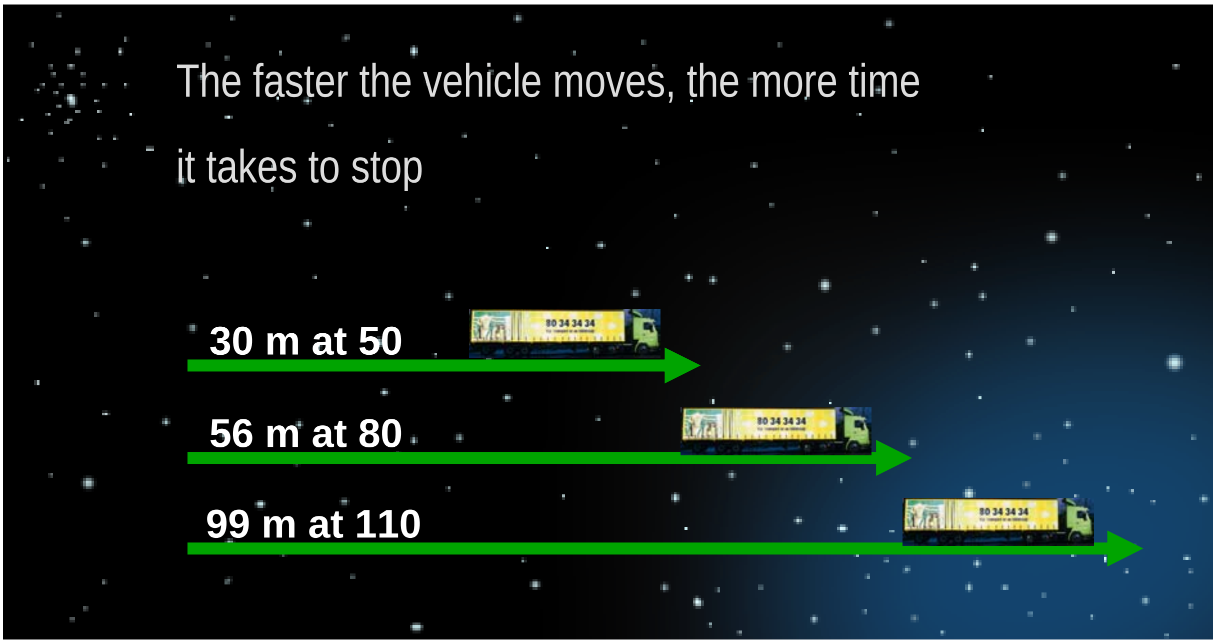


Figure 5 – Speed vs. braking distance

The casualties resulting from these multiple vehicle crashes involve other road users as well as truck drivers. Consequently, it is also considered as a workplace occupational health and safety problem besides the overall road safety issue. Although we might think that the robust design of the heavy vehicle cabin offers adequate protection for the driver, the Transport and Storage industry, however, has the highest fatality rate of any industry in Australia. For example: One-fifth of all work place deaths (59) are made up of a single occupation – Truck Driving, while a total of 103 people died as a result of road accidents in 2006-2007. These numbers do not include accidents where death or serious injury occurred to a non-working individual, for example, collision with a truck. (Safe Work Australia 2009)

To see and to be seen

To fully understand how retroreflective properties help increasing road safety for heavy vehicles, it is important to distinguish between two different aspects: one is how heavy vehicle drivers perceive the traffic signs, what they see and why they are considered as sitting in a disadvantaged position. The other aspect is how other road users perceive heavy vehicles on the roads, either stationary or moving, in other words how heavy vehicles are seen.

The following terms play a key role in how retroreflective materials work: *entrance angle, observation angle* and *cone of reflected light*.

Disadvantaged truck drivers – how they perceive traffic signage

How well we see an object during the day is determined by the amount and the colour of the light it emits compared to the amount of light given off by its environment. The light can be emitted by the object, for example by an active lighting system, a lightbulb or a lamp, or reflected from the surface of the object.

Retroreflection is the returning of light from a given surface directly back to its light source. In case of traffic signage, from the headlight of a motor vehicle illuminating the sign and returning that light back to the driver. The angles that influence the return of light are known as *the entrance angle* and *the observation angle* and the returned light is referred to as the cone of reflected light or divergence cone. The entrance angle is the angle formed between a light beam striking a surface at some point and a line perpendicular to the surface at the same point. *The entrance angle* continuously changes as a car moves toward the sign as the angle increases. (Figure 6) All retroreflective sheeting materials have lower retroreflectivity at wider entrance angles, but there are sign sheetings which are specifically designed to perform well at wide or extreme angles. *Observation angle* is the angle between the line formed by the source of the light beam striking the surface and the retroreflected beam returned to the driver's eyes. In other words, the size of the angle is determined by the vertical distance between the headlight of the vehicle and the driver's eye level. (Figure 7)

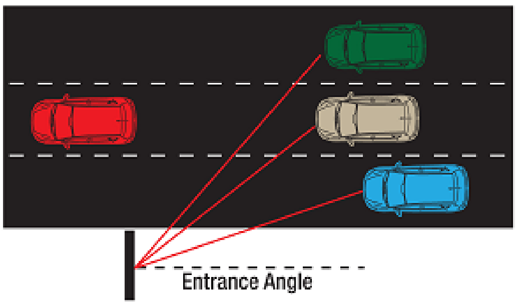


Figure 6 – Entrance angle

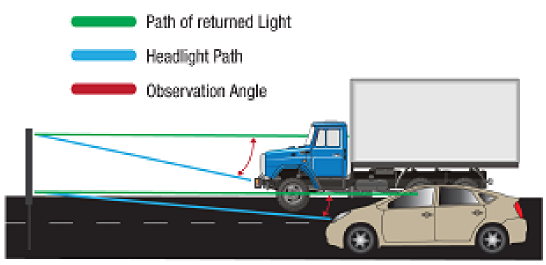


Figure 7 – Observation angle

The observation angle is significantly larger for truck drivers than motorists in cars, because of their larger vertical displacement from the headlights. This causes a significant reduction in the amount of returned light received by the truck driver, compared to the light received by the driver of the car. In case of reading traffic signs, less reflected light means less driver ability to detect, recognise and react to a sign. Figure 8A and B demonstrate the cone of reflected light showing that in case of Class 1 (reference to AS/NZS 1906.1:2007) sheeting, truck drivers have a limited visibility of the traffic sign, whereas Class 1X (Reference to RTA QA 3400) sheeting offers an increased light return efficiency and it accommodates all relevant angles, thus meets the needs of diverse road users, including truck occupants.

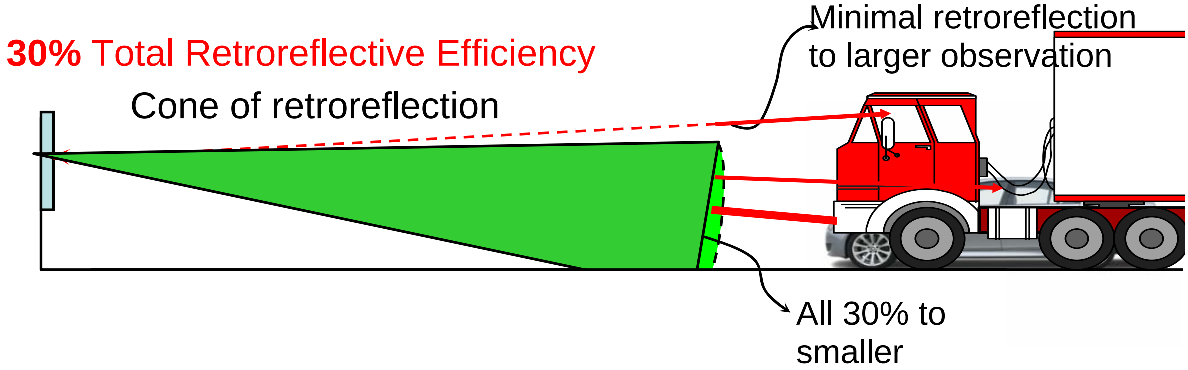
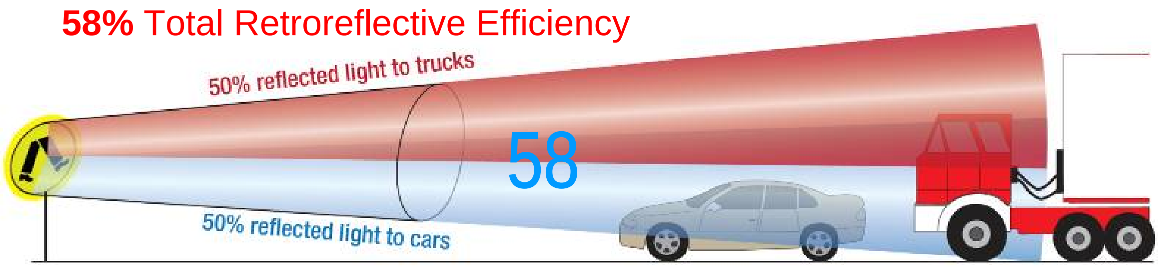


Figure 8A – Light return efficiency of Class 1 sheeting, 3M™ High Intensity Prismatic™ Sheeting



Figures 8B – Light return efficiency of Class 1X sheeting, 3M™ Diamond Grade™ DG3 Retroreflective Sheeting

All vehicles will have differing observation angles as the vertical height difference between the headlight and the driver are not all the same. This is especially obvious when you consider the difference between a car and a truck where a car at 200 metres may have a 0.20 observation angles and a truck 0.50. This differential has a large impact on the light returned from a sign and in some cases a sign that may be visible from a car is not visible from a truck. This is because the cone of reflection is not wide enough to be able to return light to the wider angle of the truck driver. (Figures 8A and B)

Disadvantaged truck drivers – how they are seen

Every year needless crashes occur because some drivers don't see other vehicles, or see them too late to avoid a collision. Many of these crashes involve smaller vehicles colliding with trucks and other heavy vehicles.

What is the problem with our vision? Why do not we detect these vehicles? The light that we observe from an illuminated or reflective surface gives us what is described as 'luminance'. This is what road users actually see. Besides luminance, however, contrast is equally important to distinguish objects, in our case, heavy vehicles from their background. This contrast is determined by the difference in colour and brightness of the vehicle and other objects in its surrounding environment. If we have a higher contrast, objects are more conspicuous, and easier to detect.

At night most of the objects blend into their environment and we are not able to distinguish them. The contrast sensitivity of the human eye is conditioned by and adapts to the ambient light of the surrounding area. In dark surroundings, contrast sensitivity is reduced; it is more difficult to detect objects from the background. It is especially true for older drivers as this contrast sensitivity deteriorates with age. In the same way it is impossible to read a newspaper in dark surroundings, it will be much more difficult to detect trucks or trailers at night, especially in dark rural areas.

There are strict regulations on active lighting fittings of a heavy vehicle. Nevertheless, these lamps require power to work properly and while they definitely play a key role in improving heavy vehicle conspicuity, these lamps do not operate when there is a power failure or when the vehicle is parked along the roadside. Passive, retroreflective markings on the other hand do not involve any power as they use the lights from other vehicles' headlamps and simply reflect it back to the driver of the approaching vehicle.

Retroreflective markings that are especially designed for moving objects have unique performance characteristics that are different from traffic signage sheetings. They are required to meet global, UN regulations on wide angle materials to make trucks visible in all situations, moving, turning or parking. These regulations have not yet been mandated in Australia, so regulatory professionals and fleet safety managers can play a particularly influential role in improving heavy vehicle visibility and safety by initiating the use of the appropriate reflective markings.

Global vehicle regulations and Australia

In 1958 an Agreement was born, formally titled "Agreement concerning the adoption of uniform technical prescriptions for wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles and the conditions for reciprocal recognition of approvals granted on the basis of these prescriptions". All participating countries agree on a common set of ECE regulations for type approval of vehicles and components and their reciprocal recognition.
The UNECE has overseen the harmonization of vehicle regulations related to heavy vehicle visibility: UN Reg. 48 - The Installation of Lighting and Light Signalling Devices and UN Reg. 104 the Uniform Provisions concerning the Approval of Retro-reflective Markings. UN Reg. 48 regulates the requirements on the installation on lighting and light-signalling devices. It governs the visibility requirements of the rear and the side of a heavy vehicle and applies to categories like M, N and trailers equal to category O. The regulation prescribes the colours to be used; white or yellow to the side and red and yellow to the rear. It provides detailed guidance on full, partial or line contour markings and how these should be applied. Table 1 presents a brief summary of the categories administered by UN Reg. 48. and optional and mandatory conspicuity markings.

SCOPE	**PROHIBITED**	<u>**International categories**</u> : **- M1** **- O1**	**Passenger cars** **Trailers less than 750 kgs.**
	OPTIONAL	<u>**International categories**</u> : **- N1** **- N2 <7.5 tons** **- O2**	**- N1 : Vehicles used for the carriage of goods with a maximum mass not exceeding 3.5 tonnes** **- N2 <7.5 tons Vehicles used for the carriage of goods with a maximum mass exceeding 3.5 tonnes but not exceeding 7.5 tonnes** **- O2: Trailers with a maximum mass exceeding 0.750 tonnes but not exceeding 3.5 tonnes**
	MANDATORY For vehicles above 6m in length and 2.1m in width	<u>**International categories**</u> **- N2 > 7.5 tons** **- N3** **- 03** **- O4**	**- N2 > 7.5 tons** **- Vehicles used for the carriage of goods with a maximum mass exceeding 7.5 tonnes but not exceeding 12 tonnes and above 6M in length and 2.1 m in width** **- N3 : Vehicles used for the carriage of goods with a maximum mass exceeding 12 tonnes and above 6m in length and 2.1 m in width.** **- 03 : Trailers with a minimum mass exceeding 3.5 tonnes** **- O4: Trailers with a minimum mass exceeding 10 tonnes**

Table 1 – Optional and Mandatory conspicuity markings for vehicle categories according to UN Reg. 48

The provisions of UN ECE Regulation 104 apply to the approval of retro-reflective markings designed to increase the visibility and recognition for heavy and long vehicles and their trailers explaining the performance requirements. Contour markings are classified as type “C” and the intention of placing retroreflective tapes on the side and at the rear of the vehicle is to make its shape and dimensions fully visible for other road users. Retroreflective tapes used on heavy vehicles and their trailers shall meet the strict requirements defined in UN ECE Reg. 104 which include photometric and colorimetric specifications, dimensional properties and physical and chemical testing expectations. Contour marking materials tested and approved according to UN ECE Reg. 104 shall have the approval mark printed on the surface of the tape showing classification ‘C’, country where the approval was granted and the approval number. This regulation also offers guidance for the marking shape and mounting requirements. Examples of marking variations are shown in Appendix 1.

In Europe, governments tried to minimize the negative impacts of heavy vehicle accidents by introducing a national legislation, but as new technologies and borderless trade evolved there was a crucial need to harmonize the international requirements which led to a new European Directive 2007/35/CE, effective from July 2008. The European Union has decided to implement mandatory conspicuity markings for heavy goods vehicles and trailers in all member states from July 2011. The technical, application and performance requirements follow UN Regulations 48 and 104. This is an excellent example of how the adoption of the high performance retroreflective sheeting for usage in vehicle marking has resulted in another safety improvement for many road users.

In the United States the two main federal regulations have a longer history than Europe. The Federal Motor Vehicle Standard 108 / Part 571 define the technical requirements and the certification for retroreflective tapes on heavy vehicles. Its purpose is to reduce traffic crashes and deaths and injuries resulting from traffic crashes, by providing adequate illumination of the roadway, and by enhancing the conspicuity of motor vehicles on the public roads so that their presence is perceived and their signals understood, both in daylight and in darkness or other conditions of reduced visibility. (FMVSS 108 (1998)) In 1993 an OEM regulation by FHWA required conspicuity markings on all new trailers over 4.5 tonnes and the retrofit regulation of 1998 mandated these markings on all existing trailers over 4.5 tonnes.

In Australia the Vehicle Standard (Australian Design Rule 13/00 – Installation of Lighting and Light Signalling Devices on other than L-Group Vehicles) 2005, or in an abbreviated form, ADR 13, refers to conspicuity markings permitting conspicuity markings according to UN Reg. 48 and UN ECE Reg 104. ADR 13 has adopted the full text of UN Reg. 48, but has not yet mandated conspicuity markings as stated in UN Reg. 48.

As retroreflective markings substantially add to the visibility of heavy vehicles and their trailers from all angles at a relatively low cost, it should be considered to adopt the mandatory vehicle marking guidelines by UN Reg 48 and 104 and increase standards in Australia to improve safety.

Research studies on heavy vehicle visibility

Numerous reports are available about the effectiveness of visibility markings aiming at reducing rear and lateral collisions. As we discussed in previous chapters, visual perception is limited at night which results in relevant information not being received and more attention being required of the motorist. In this situation, trucks, which normally move relatively slowly, represent a potentially dangerous obstacle, especially since the fatality rates for drivers of passenger cars involved in accidents with them are very high on account of the high mass of the trucks. About 40% of road accidents take place at night, dawn or dusk in spite of the fact that not more than a third of the traffic is on the roads (compared to day-time driving). It can be concluded that driving at night is at least twice as dangerous as during the day. (Schmidt-Clausen 2000)

The National Highway Traffic Safety Administration USA (NHTSA) has studied the effectiveness of retroreflective conspicuity tape on heavy trailers. (Morgan 2001) In an effort to quantify the effectiveness of the retroreflective tape requirement on heavy trailers, NHTSA made arrangements with the Florida Highway Patrol and the Pennsylvania State Police to collect data and compile statistics on whether or not retroreflective tape was installed on heavy trailers involved in crashes. Data was collected on 10,959 cases in these two states. The study concluded that the usage of retroreflective tapes on trucks was effective and significant reductions could be achieved in side and rear impacts. In dark conditions defined as dark: not lighted, dark: lighted, dusk and dawn periods, the use of retroreflective tape reduced overall side and rear impacts into heavy trailers by 29 percent. In dark-not-lighted conditions the use of retroreflective tape reduced side and rear impacts by 41 percent. The study also declared that severe crashes were decreased by 44% and that the use of reflective tapes was especially effective in rain and fog conditions.

The German technical University of Darmstadt had also conducted an examination of night time and day time accidents between a test group comprising 1000 vehicles equipped with contour markings and a control group of 1000 vehicles without such measures. After 2 years of the installations the conclusion was drawn that 95% of night time collisions could have been avoided if trucks of the control group would have had retro-reflective visibility markings. The results of increased truck visibility demonstrated that 41% reduction of rear end crashes and 37% decrease of side impacts could be achieved by applying reflective, outline markings on heavy vehicles. The data analysis had also confirmed that the risk of an accident between truck and car was 30 times greater without conspicuity markings. (Schmidt-Clausen 2000)

Another study commissioned by the European Union and accomplished by the German TUV Rheinland Group in 2004 outlines the situation in the individual member states of the European Union. The study investigated the effects of a mandatory introduction of conspicuity markings for heavy vehicles by creating a detailed cost-benefit analysis for decision makers. 390 million Euro savings had been calculated annually in EU 15 countries only, by taking the costs of the markings and the potential crash reductions into account. This calculation was based on the number of accidents that can be prevented by using the contour markings and the social benefits resulting from this. The cost benefit ratio can achieve factor 4 in case of heavy vehicles over 3.5 tonnes, whereas with vehicles over 12 tons it can reach factor 6. Calculations include the assumed economic lifetime of the markings and the timeframe of 6-12 years necessary for applying markings on all European trucks. (TUV 2004)

It is important to gain understanding of global research projects, but it is also imperative to become aware of where Australia stands compared to other countries. Unfortunately, no specific studies are available in Australia concerning heavy vehicle visibility and reflective markings, but there was a detailed report created on the safety performance of the heavy vehicle industry, benchmarking it against selected OECD countries. The study focused on fatality rates involving trucks with a gross vehicle mass rating exceeding 4.5 tonnes. The study found that Australia's heavy vehicle fatality rate per kilometre travelled is 47% higher than the USA, 39% higher than the UK, comparable to Germany & Canada, 20% lower than Sweden, 45% lower than France, and 55% lower than New Zealand. (Haworth et al., 2002) The analysis has revealed the different characteristics of Australian truck fatalities, for example the percentage of truck occupants killed is higher in Australia (19%) than in other countries, 10 and 16%, so it is needless to say that driving a truck is one of the most dangerous occupations in Australia. The study also recommends introducing protective devices for other road users than truck occupants adopting rear and lateral underrun protection to reduce the overall fatality rates involving heavy vehicles. It cannot be disputed that underrun protection would definitely contribute to saving lives on the roads; however it focuses on alleviating the effects of an impact and not on prevention. On the other hand, visibility markings are applied to prevent fatal, serious or light injury crashes by being able to detect and recognise a truck on time and by being able to react safely.

Equipping a truck and a semi trailer with retroreflective tapes would cost approximately $1,000 (AUD) which is a low cost intervention, in fact, less than 2 full tanks of fuel for a prime mover, especially when we compare it to the savings that could be achieved. Heavy vehicle accidents are over-represented in the road fatalities statistics and a fatal crash creates a burden of $1.7 million on society (aaa.asn website). Investing into making trucks safer would save more on economic costs than the money charged for the material and application, and would definitely have a positive impact on saving more lives on our roads.

Conclusion

The readily available vehicle and road markings technologies should be leveraged to improve road safety for all Australian road users. The adoption of the high performance, UN ECE 104 certified retroreflective tapes for usage in vehicle visibility marking is another safety improvement for both heavy vehicle drivers and other road users. A review of the relevant ADR standards needs to be undertaken to take into consideration the latest technology and the global best practice to evaluate the mandatory introduction of visibility markings for heavy vehicles. As long as formal programmes are not put into place, the support of voluntary fleet applications by insurance premiums or other financial incentives, for example, tax deductions, subsidy of the cost of markings, no accident policy and government funding would be necessary. Further research needs to be carried out to understand the differences and similarities between Australia and the rest of the world complemented by consistent accident data collection to support programme evaluation, before and after studies.

Governments at both state and federal levels need to be more proactive and evaluate and exploit these new, highly cost-effective technologies to advance road safety.

References

ETSC Fact Sheet (2006): Conspicuity and Road Safety No. 09

Haworth, N. and Symmons, M. (2003) Monash University Accident Research Centre „Review of truck safety - Stage 2: update of crash statistics" Report no. 205, iii

Haworth, N., Vulcan, P. and Sweatman, P. (2002) National Road Transport Commission, "Truck Safety Benchmarking Study", ISBN: 1 877093 08 4, Summary, 4-7

IRF Position Paper (2004) "Incorporating UN ECE Regulation 104 into EU law will save lives"

LBI Unfallforschung Austria (2001): "Viewing Behaviour Survey to determine the perceivability of heavy goods vehicles with contour markings"

Morgan, C. (2001) "The effectiveness of retroreflective tape on heavy trailers", National Highway Traffic Safety Administration, US Department of Transportation, Report no.: DOT HS 809 222, NHTSA Technical Report

Prof. Dr.-Ing. Schmidt-Clausen, H.J. (2000) Laboratory of Lighting Technology, Darmstadt University of Technology: "Contour Marking of Vehicles" Final Report FO 76 / 00, 8

Safe Work Australia (2009) Work related traumatic injury fatalities, Australia 2006-2007, 9

TUV Final Report 2004: Conspicuity of heavy goods vehicles, Contract Number: SER-B27020B-E3-2003-Conspicuity-S07.28185

Data sources

AS/NZS 1906.1:2007 Retroreflective materials and devices for road traffic control purposes, Part 1: Retroreflective sheeting

Code of Federal Regulations, (2004) Federal Motor Vehicle Safety Standards 108, Part 571, Title 49, Volume 5, CITE: 49CFR571.108, 239-313

Fatal Heavy Vehicle Crashes Australia quarterly bulletin July-September 2010 - Australian Government, Department of Infrastructure and Transport, Bureau of Infrastructure, Transport and Regional Economics, ISSN 1835-0240

http://www.aaa.asn.au/saferroads/Cost.asp

Regulation No. 48 (2008) “Uniform provisions concerning the approval of vehicles with regard to the installation of lighting and light-signalling devices” Rev.1/Add.47/Rev.5 United Nations

Regulation No. 104 (1998) “Uniform provisions concerning the approval of retro-reflective markings for heavy and long vehicles and their trailers” Rev.2/Add.103, United Nations

Road Death Australia September 2010 – Australian Government, Department of Infrastructure and Transport, Bureau of Infrastructure, Transport and Regional Economics, ISSN 1449-1168

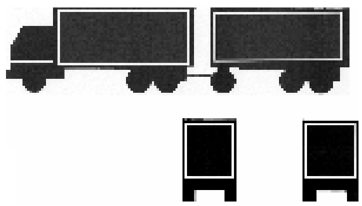
RTA QA Specification 3400 (2009) Manufacture and delivery of road signs, Edition 7 / Revision 1

Appendix 1

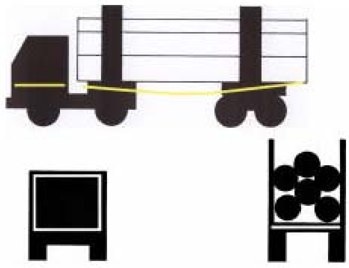
Examples of retroreflective markings according to UN ECE 104

1.

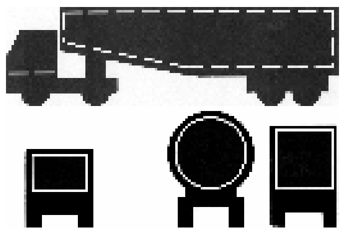
2.



3.



4.



5.