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Keeping people safer through better visibility
Advances in retroreflective technologies for road signage, pavement markings and vehicle visibility delivering safer roads

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Abstract

The use of retro-reflective materials in guiding road users and delineating roadways at night have been in use for over 70 years and is still a key part of the road safety infrastructure on our roads today. The importance of effective road signage and line marking can be underestimated when seeking road safety solutions and an understanding of the new technologies available can give road safety practitioners a better toolkit when they are searching for lower costs, but effective solutions in improving road user safety.

This presentation looks to communicate a basic understanding of the science behind retro-reflective materials as well as the new technologies that are available in the market. It looks at how these materials affect different road users including older drivers as well as those in larger vehicles such as trucks. It includes current global perspective on the use of these materials including research, international standards and best practice from other countries as well as Australasian solutions for road safety creating better and safer places to travel and live.

Key words
Road safety, sign management, pavement markings, retroreflectivity, visibility, conspicuity

1.Introduction

Overall the paper covers Road Signage. Pavement Markings and Vehicle Visibility Solutions and the way advancements in retro-reflective technologies have resulted in cost effective road safety outcomes for road users around the world and Australasia. By gaining a greater understanding on the use and the cost / benefit ratios of these materials governments can make more informative decisions about the materials selected and the appropriate applications on their road networks

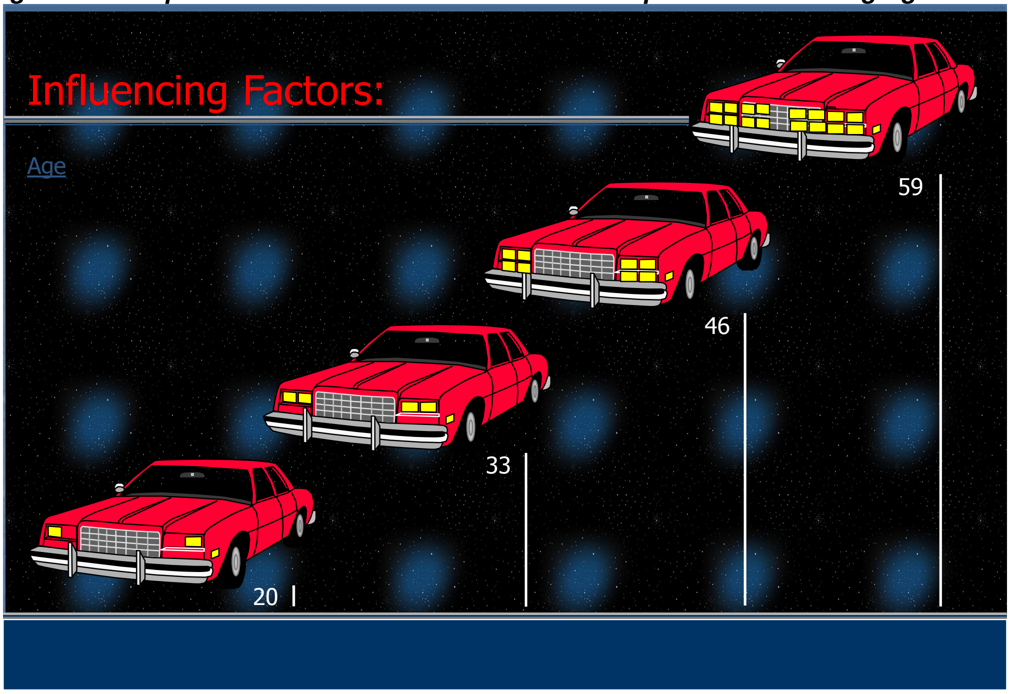
This presentation draws information and knowledge of the global market place as well as informed technical information on retro-reflective sheeting materials from industry and market expertise. It looks to be informative and relate this technology and use to practical road safety outcomes to all levels of road safety practitioners as well as communicate the cost effectiveness in the use of these advanced materials. Since 2010 several pilot and actual applications have been initiated and selected by state road authorities and local governments where one of the main objectives included continuous monitoring and data collection for better evaluation. The paper will provide an overview of these projects by providing the data collected and the analysis conducted. A special attention is given to wet visibility of lines and cost benefit calculations to assess what solutions offer the optimum fit for diverse traffic conditions, projects like the M5 motorway or Mona Vale Rd applications (NSW) will be discussed.

Signage and line marking are some of the most basic elements of road safety infrastructure in which Government and road safety practitioners can control, yet their effective use and advancement in technologies is not well understood. This paper aims to give a high level overview of the road safety impacts of effective signage, line markings and increased vehicle visibility and also makes an attempt to illustrate the gap between actual applications and standards. The NSW RMS have been proactive in trialling new reflective technologies designed to increase sign visibility for motorists and introduced a new specification above the current Australian standard to apply these new technologies in practice which clearly demonstrate increased safety.

2. Changing environment

The driving environment has changed with a larger amount of traffic, more aging drivers, altered headlamp performance and diverse vehicle sizes. It has coupled with increased distractions, both on the roadside environment and also within the vehicle such as the use of mobile phone type devices and in-vehicle driver aids, such navigation systems.
The Intergenerational Report (2010) states that the proportion of people aged over 65 years is rising and the number of people aged 65-85 years is expected to more than double and the number of people 85 and over more than quadruple until 2050. Aging results in a natural decline in vision (night-time acuity) and motor (physical) functioning.
As the ageing population are also road users, their needs in navigating the roads need to be understood in order to improve safety. Older drivers usually have trouble navigating roads, which were not designed with them in mind. For many of these motorists signs are hard to read, lanes are too narrow and right hand turns are very difficult.
It is understood that as we age our need for light to be able to read doubles around every 13 years after the age of 20. Drivers over the age of 60 require approximately 8 times more light and their reaction times increases, needing around 40% more time to react than younger drivers. (Marland, 1967)

Figure 1 – Graphic demonstration of illumination requirements with aging drivers.



Headlamp performance has also changed. Several motor vehicle models do not provide sufficient illumination towards erected signs. Currently about 80 percent of late model vehicles are factory-equipped with visually/optically aimable (VOA) headlamps that compromise sign performance and reduce the visibility of the signs significantly. (Sivak et al., 2000)

Besides an ageing population and headlamp performance, the diversity of vehicles also affects sign performance. The wide range of vehicle sizes on the roads – from motorbikes to prime movers produces a wide range of observation angles; 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. Therefore, 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. As drivers of these vehicles can sit up to 2 metres above their headlights, the amount of luminance they receive from the sign can be as low as one third that of a driver in a conventional sedan. Less reflected light means less driver ability to detect, recognise and read a sign.

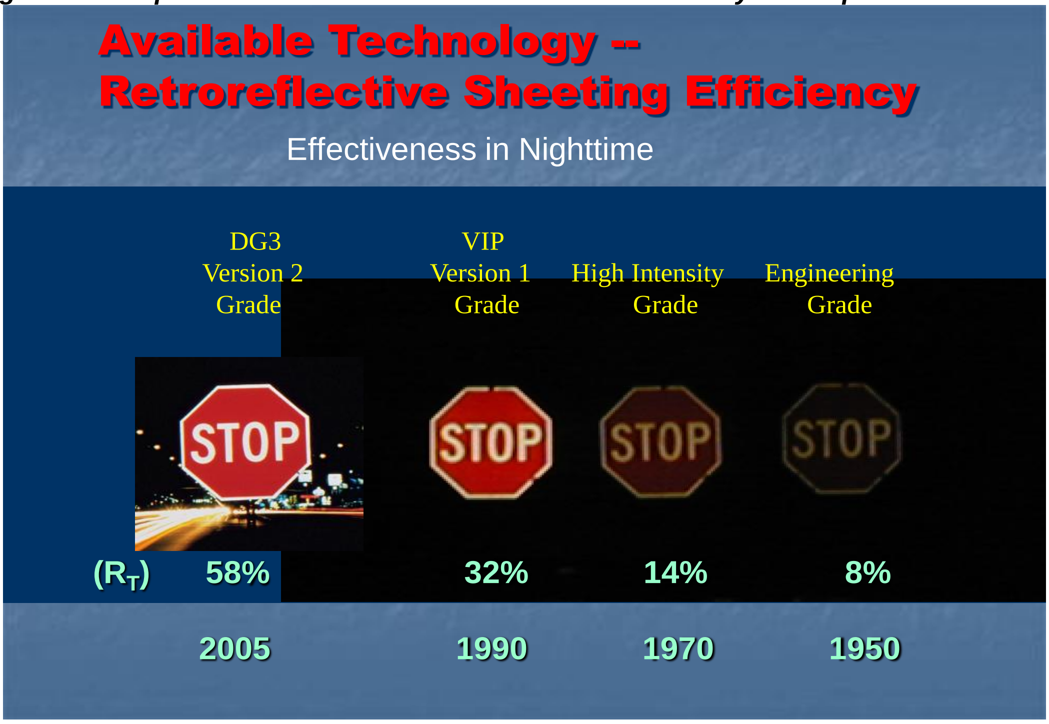
All these three factors mentioned above and their relationship to sign visibility has serious implications on road safety. Thus, clear, conspicuous and legible signage to improve driver safety is essential. This is especially important when driving at night as conditions are generally acknowledged as more difficult to navigate safely.

3. Advancements in technologies – Signage

The development of retroreflective sheeting materials dates back to the 1930's and since this time it has seen some major developments in improving the efficiency of the sheeting with advance in technologies at a microscopic level. The original products produced used the glass bead technology that is still in use today. Enclosed lens beaded sheetings were developed in the 1940s, these represent Class 2 in AS/NZS 1906 standard, or Type I in ASTM. Prismatic technologies have been around since the 1980's doubling the returned light compared to enclosed glass beaded sheetings and providing a performance of 32% of light directed back to the driver. The real breakthrough in technologies, however, arrived in 2005 with the introduction of 3M's Diamond Grade™ DG3 Full Cubed technology that reworked the structure of the existing microprisms in the sheeting (Figure 2). This has been achieved by designing a prism geometry called Micro Full Cube, or simply Full Cube Technology. In effect the full cube reflective sheeting design takes the reflective area of the microprismatic (cube corner) design and discards the ineffective corners. These reflective centres are replicated side by side to create a 100% retroreflective surface. When viewed in this fashion it appears a trivial development but in reality it is far from that. With the full cube prismatic design, the actual efficiency of the material is 58% once physical losses have been accounted for. That means 58% of the light which strikes the sign face is retroreflected to the driver in the cone of retroreflection.

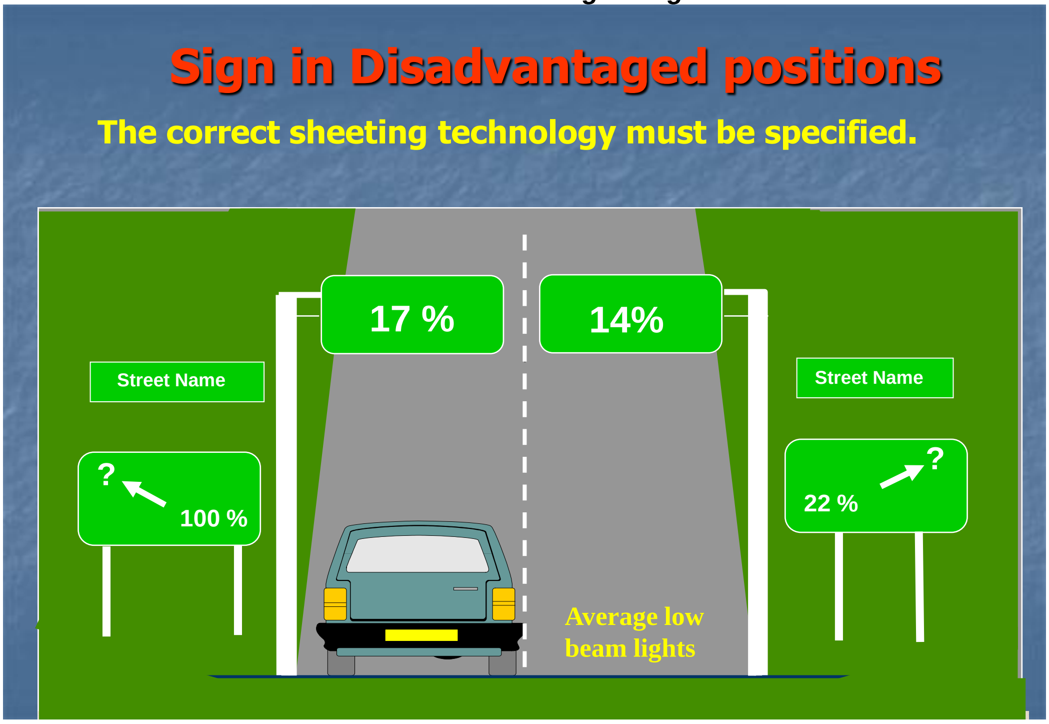
As would be argued by many road users, the brightness of many signs do not need to be increased to improve their legibility. With the Full Cubed sheeting the increased efficiency is engineered to create a broader cone of reflection, thus using the additional light produced to reflect to broader range of observation and entrance angles. By carefully controlling the divergence, the light can be distributed without becoming blinding to any driver. In other words, retroreflectivity at narrow observation angles can be kept relatively equal to that of incumbent high performance sheeting, while retroreflectivity at wider observation angles has been significantly increased.

Figure 2 – Graphic demonstration of retroreflective efficiency development since 1950.



The big advantages in this Full Cube technology is that it provides greater luminance to large vehicles such as trucks that have a large observation angles. It also provides all vehicles greater light reflectivity from disadvantaged sign positions such as signage on the right hand side of the road, overhead gantry positions and winding roads where vehicles headlights do not focus as much light on the sign. (Holderness, 2011)
The illustration below shows the amount or percentage of light returned from the modern road signage positioning;

Figure 3 - Shows the light return of signs to drivers indicating the performance drop off for wide observation angled signs*.*



There is also an advantage in the brightness to cater for older drivers and the current move toward the new VOA headlights in new cars which accurately limits the beam angle of headlights. By providing more light to the driver of all vehicle types and improving the sign legibility for disadvantaged signs, 3M's DG3 sheeting is seen as a breakthrough in improving the ability of drivers to read road signage and providing better road safety outcomes.

3.1 Case Study 1 – Sign assessment on a major motorway NSW

Date: July 2011

Signs: 50 traffic signs including guide and regulatory signs

Average age: 10 years

Reference: AS/NZS 1906.1:2007

Performance: 84% of the signs performed above or close to new sheeting values

50 signs were assessed on a major motorway in NSW in 2011. Signs were measured according to ASTM 1709, with a minimum of 4 data points on each colour and then the values averaged. The measurement device used was Delta Retrosign GR3, a certified retroreflectometer calibrated by the manufacturer in December 2010. The instrument was calibrated before measurements were taken using the reference cap supplied by the manufacturer. This device is able to measure various observation angles at 0.2, 0.5 and 1.0 degree and provides simultaneous values for all these three angles. 1.0 degree angle value is especially important for disadvantaged observation angle positions, like truck drivers.
Signs were only cleaned if they had excessive dirt or dew on their signfaces, otherwise were measured without cleaning. The assessment included left, right and gantry mounted signs. Each sign was made either by using sign sheeting Class 1 or Class 2 (AS/NZS 1906.1:2007) or the combination of these two classes. The colours inspected contained white, red, green, blue and yellow. No fluorescent signs were part of the assessment. Measured values were referenced to AS/NZS 1906.1:2007 although this standard was not in place before 2007 when most of the signs were made. Measured values were referenced to 80% of residual performance values after outdoor exposure. For simplicity, Class 2 sheetings were also referenced to 80% of residual performance instead of 50%.
Table 1 illustrates an extract of the data sheet showing two signs and their measured performance. While sign no. 1 performs above the expected residual 80% after 10 years, the 'end motorway' sign shows some defects and cleaning marks when assessed at night time. This sign would probably look satisfactory during daytime inspection as these marks are not visible during the day. Sign performance falls below the standard, so it is recommended to replace this sign.

Summary: In general the signs assessed were well maintained and 84% of the signs inspected performed above or close to new sheeting values. Retroreflective performance was excellent even at higher observation angles which provide safe guidance for truck drivers and other road users sitting further away from their headlights. Class 1 signs had a manufacturer's warranty of ten years and it is assumed that with careful maintenance the majority of the signs will provide safe navigation for drivers for additional years.
As retroreflectivity degrades over time, these inspections are recommended to be repeated annually.

Table 1 – extract from data table, measured values referenced to AS/NZS 106.1:2007, Class 1

				Colour			
Sign No.	Photo	Entrance angle, 4^0	Observation angle	White cd/lx/m2	Residual performance 80%	Measured data cd/lx/m2	Perf. Acc. To standard
1		4	0.2	250	200	212.40	ok
			0.5	95	76	78.40	ok
			1	10	8	26.80	ok
			Observation angle	Blue cd/lx/m2	Residual performance 80%	Measured data cd/lx/m2	Perf. Acc. To standard
			0.2	12	9.6	15.00	ok
			0.5	5	4	5.50	ok
			1	0	0	2.25	ok
12			Observation angle	White cd/lx/m2	Residual performance 80%	Measured data cd/lx/m2	Perf. Acc. To standard
			0.2	250	200	160.00	fail
			0.5	95	76	70.00	fail
			1	10	8	12.80	ok
			Observation angle	Green cd/lx/m2	Residual performance 80%	Measured data cd/lx/m2	Perf. Acc. To standard
			0.2	25	20	21.2	ok
			0.5	9	7.2	9.4	ok
			1	1	0.8	2	ok

4. Line Marking

Increasing the visibility of the road ahead decreases the likelihood of drivers losing control of their vehicle and either crossing the centre line or running off the road. Following recent efforts to increase the brightness of roadmarkings in New Zealand, a number of studies have attempted to quantify the associated reduction in the likelihood of a crash, but with limited success.

A research project, which was conducted between 2008 and 2010, aimed to trial a new method of observing drivers' reactions to the roading context, in order to establish the effect of improved road delineation on driving behaviour.

The visibility of roadmarkings is a key factor in maintaining lane position while driving. The importance of bright roadmarkings is particularly apparent when driving in reduced-visibility conditions, such as when driving at night, or in wet weather. The incidence of road accidents is estimated to increase by 40% at night and by 70% in wet weather conditions (Andrey and Yagar, 1993).

Drivers rely on roadmarkings to provide a short-range view for lane-keeping, and a longer-range view of upcoming changes in the road geometry. Successful horizontal curve negotiation relies on previewing upcoming curves about 1–2 seconds in advance. In 1999, European research used driving simulator experiments to examine the minimum threshold of sight distance of the road ahead that was required to navigate successfully (European Co-operation in the Field of Scientific and Technical Research 1999). They found that drivers adapted to sight distances of 1.8–2.7 seconds by reducing their speed and the variation in their lateral position on the road. Drivers began to fail to navigate horizontal curves when sight distances were 1.2–1.8 seconds. Consequently, they recommended that drivers should be able to preview roadmarkings at an absolute minimum of 1.8 seconds in advance (the equivalent of a 50m sight distance when travelling at 100kph). (Walton et al, 2011)

Table 2 shows the visibility of 100 mm edge lines for reflectorised and non-reflectorised lines for young drivers (15 to 35 years) and older drivers (65 to 75 years) on unlighted roads, expressed as forward viewing time at 100 km/h driving speed. At 50 km/h the distance seen is unchanged, but the viewing time ahead is doubled from that shown.

Table 2 - showing the view forward time comparisons of young and older drivers.(Dravitzki et al)

Table 2 Visibility of 100 mm edge line roadmarkings, expressed as seconds of forward viewing time when travelling at 100 km/h. Driver age	**Visibility of markings (seconds)**							
	Non-reflectorised marking				Reflectorised marking			
	Dipped		Full beam		Dipped		Full beam	
	New	Old	New	Old	New	Old	New	Old
Young driver	2.7	2.0	3.0	2.2	3.3	2.7	4.4	3.0
Older driver	2.1	1.3	2.3	1.5	2.8	2.1	3.4	2.3

4.1 Advancements in technologies – Road Marking

All of us can agree that one of the fundamental needs for road users is a safe road network. Safety includes several factors ranging from legible and visible signage, traffic signals, through forgiving road planning to safe line markings. Much of the time, line marking is taken for granted. It must be highlighted, however, that effective delineation improves the safety of our roads by helping motorists to process traffic information quickly, thus making the right decision and navigating safely. Similarly to sign performance, line visibility deteriorates over time and the ability to retroreflect light back to the light source at night to the drivers' eyes decreases. The environment, the pavement surface and the traffic volume all influence line quality and durability.

No one can dispute that lines should be visible not only in dry weather, but also in rainy and wet conditions. Brodsky and Hakkert (1988) found the increased danger in driving in wet conditions with accidents rates increases up to three times of that in the dry. A large part of the difficulty in driving in the wet stems from the inability to find the delineation of the road between lanes and the verge. Basically, road line markings become difficult or impossible to see and vehicles can find themselves in the wrong lanes or on the wrong side of the road. Like older retroreflective road signage, line marking uses glass bead technology to be able to retroreflect the lines back to the driver to give them visibility during the night. The technology is proven and is used in all types of line marking materials such as paints, thermoplastics, tapes and other materials. However, because of the physical properties of the glass beads when water is applied to the surface, the retroreflection is refracted and the visibility of the line is reduced.

Wet reflective optical elements, a breakthrough technology incorporating special optical elements to provide wet reflective properties in linemarking, already exists and is utilised in many solutions ranging from paint through thermoplastic to durable tapes. The technical reason for not being able to see the lines 7 in the wet is that the refractive index of the glass bead is 1.5 – 1.9 and to be able to reflect with water over a surface a refractive index of 2.4 is required. 2.4 are about the refractive index of a diamond.

In recent years 3M has released a microcrystalline ceramic element that is able to attain the 2.4 refractive index and is now been utilised in many road line marking systems. This structure is pictured in Figures 4 and 5, embedded in paint alongside a glass bead and is called an "optical element". Figure 5 shows a macro view of elements and beads in a linemarking.

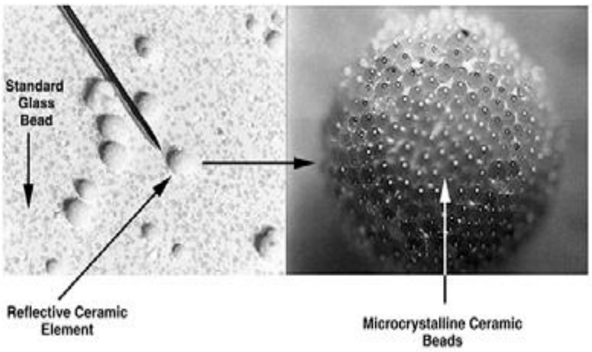


Figure 4 – 3M wet reflective optical elements

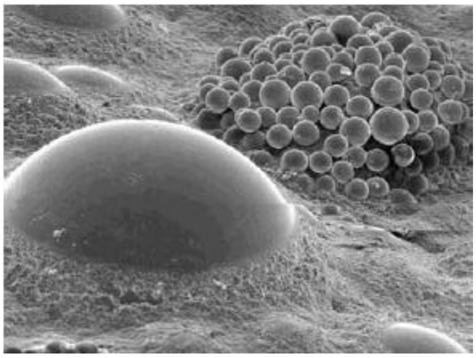


Figure 5– Magnified image of glassbead and 3M elements

Standards and Roading Authority specifications, there is a need for performance based specifications, such as AS 4049 series standards– Paints and related materials: Pavement Marking Materials, define the performance criteria for linemarking materials. The standards suggest that the absolute minimum level of retroreflectivity on dry roads should be 150mcd/m2/lx, whereas in wet conditions this value should be not less than 80 mcd/m2/lx. These values represent the intervention level, i.e. the quality of the lines should never fall below these minimum requirements.

The Roading Authorities also use the standards as guidelines when establishing their own specifications and performance requirements. However variations occur between authorities, resulting in a significant range of performance levels that drivers are subjected to. This can only be addressed by applying a minimum standards level for all road markings, and that they should include reference to wet reflectivity requirements. The same reflectivity can result in different levels of visibility or brightness depending, among other things, on the driver's age, the marking width, and the position of the marking on the road.

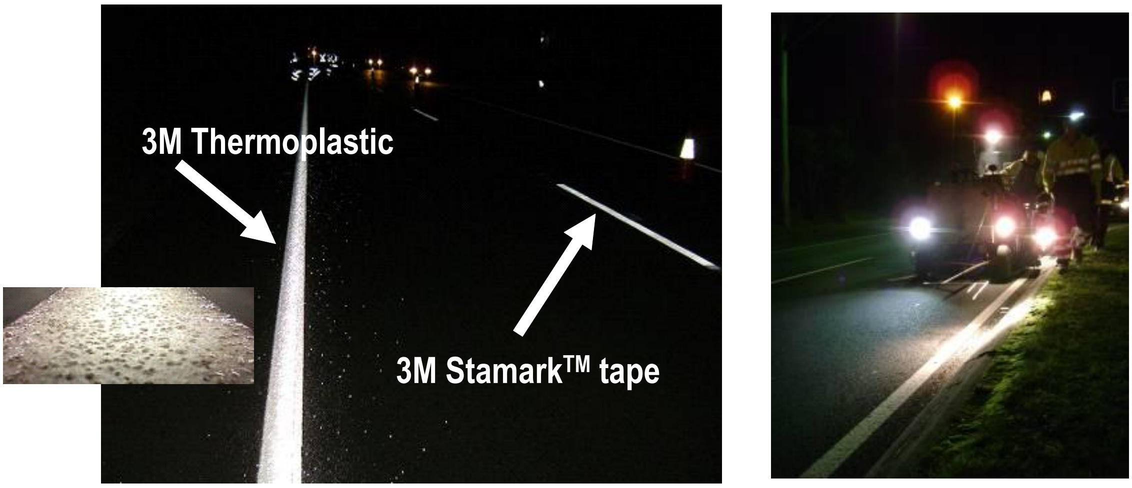
4.2 Case Study 2 – Combined all weather tape and thermoplastic project, NSW

Line marking materials used:	3M Stamark^{TM} A380 AW – wet reflective tape and 3M All Weather Thermoplastic
Application date:	June 2011
Surface:	asphalt
Line types:	tape for center lines, thermoplastic for edge lines
Problem:	**wet weather visibility on high speed road**
Performance in March 2012:	markings remained intact, excellent day and night time visibility, lines clearly visible in rainy conditions, high retroreflective readings

In June 2011, NSW RTA decided to trial all weather applications on a major arterial suburban road. Edge lines were marked with 3M All Weather Thermoplastic containing 3M wet and dry reflective element mix, center lines were installed with 3M StamarkTM wet reflective tape for additional durability as these lines suffer from most of the wheel hits. Lines were assessed after 1 month of trafficking; the techniques employed were retroreflective measurements, both dry and wet reflectivity were checked. However, instead of measuring

wet recovery, 5 sec measurements were carried out to inspect true wet and rain performance. A Zehntner 6014 device assisted the process.
The tape center lines returned values between 840-950 mcd/lx/m2, and 5 sec. wet reflectivity was on average 560 mcd/lx/m2. The thermoplastic edge lines read between 480-650 mcd/lx/m2 when dry and 220 mcd/lx/m2 after 5 sec. wet measurements. Current intervention level is specified at 150 mcd/lx/m2 for dry and 80 mcd/lx/m2 for wet in RTA QA Specification R145. Wet weather inspections of this site have confirmed that the all weather system is effective in natural rainfall events Line assessment will be repeated in April / May 2012 after 9 months trafficking.

Figure 6 - Application of 3M Stamark^{TM} and All Weather thermoplastic markings



Driving in the rain always creates a challenging situation for road users and by using durable and wet reflective pavement marking materials road owners are finally provided with a means to greatly enhance the safety and performance of their pavement markings for the times when people need it most. Furthermore, they complement the current standard requirements for the highest performance classes and provide a system compliant even with the most “rigorous” specifications. These types of markings offer a true value added benefit of increased wet night visibility and present road authorities and traffic safety professionals cost effective solutions as shown by a selection of case studies in this paper.

5. Vehicle visibility

The risk of an accident between a truck and a car is 30 times greater when a truck does not have highvisibility vehicle markings. (Morgan)
This chilling fact is a key reason why the European Union have made high-visibility truck markings compulsory in Europe under UN/ECE 104, effective from October 2011. Approximately 1,600 people are killed on Australian roads every year, and 40% of all road accidents occur at night. But why?

Figure 7 - Visual comparison of daytime and nighttime imagery.

This image graphically shows the contrast between daytime visual imagery and nighttime visual imagery. Quite simply the driver loses 95% of visual imagery when driving at night.
It mostly comes down to human factors:

- Only 5% of information we see during the day is seen at night
- A driver needs double the light to see an object to the same capacity every 13 years. A 60 year-old driver requires 8 times more light and approximately 40% more time to respond than a 20-year old. (Marland) With an ageing population, this is an ever increasing concern.

UN/ECE104 is the regulation which governs the use of retroreflective markings on heavy vehicles in European Union countries, which became mandatory from October 2011. Homologation of approved ECE104 retro-reflective materials is identified with an E-mark symbol.

The symbol is proof that the products have been tested and certified by an independent and authorised centre and meet all the requirements of ECE104. Category C (Contour) materials are the brightest materials for vehicle markings. With a brightness of 300- 450 cd/lx.m2, these films may only be used for contour (safety/conspicuity) markings. Without the E-Mark, the product is not compliant with the regulation.

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.

UNECE 104 compliant tapes are compliant for use on vehicles in Australia and New Zealand under Australian Design and New Zealand Best Practice.

Figure 8 - Rear outline visibility markings can reduce rear end collisions by up to 41%. Full vehicle marking;

Figure 9 - Side outline visibility markings can reduce side on collisions by up to 37%. **Partial vehicle marking;**

6. Recommendations and conclusions

Road signage and line marking are significant parts of the total road asset and should be maintained to a high standard to ensure maximum return on investment and road safety for the community. The recent advances in retroreflective technologies for road signage and line markings should be leveraged to improve road safety for all Australian road users. For road signage to be as effective as possible, it is important that all road users and the road environment are considered during the material design and specification stages. The current Australasian signage standard does not take into account the changing needs of the ageing population and other road users, the disadvantaged sign positions and the diverse vehicle sizes. When it comes to road signage, the fact is 'what you see during the day is not always what you see at night' and performance can differ substantially. Road authorities and traffic engineers have very little control over many factors that impact sign luminance, however they can control the specifications of the retroreflective sheeting that they use and also the effective positioning of the sign.

Some road authorities have already recognised the requirements for better performing materials and have implemented this into their specifications. It is recommended that all road authorities follow the best practices and upgrade their specifications. It is also essential that the next revision of the Australian standard reflects the changes.

With the introduction of new wet reflective line marking technologies there is now an opportunity to improve the road safety problem of line delineation in the wet. Durable marking solutions like wet reflective tapes have proven their cost effectiveness over other, traditional solutions. Additionally, they complement the current standard requirements for the highest performance classes and provide a system compliant even with the most "rigorous" specifications. All Weather markings offer a true value added benefit of increased wet night visibility and present road authorities and traffic safety professionals cost effective solutions. Further work and investigation are called for on upgrading the standards and the specifications to include the need for wet and rain night visibility in all states.

The readily available vehicle visibility technologies should also be leveraged to improve road safety for all Australasian 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.
The local best practice examples represent how proactive our local governments and road authorities are in trialling new technologies to increase sign and line visibility for motorists. As road users rely on road authorities, they have to be more assertive at exploring the increased safety and financial benefits in implementing these new technologies.

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