Project Number: 5-28210.00

Older driver infrastructure and vehicle issues- background paper for the AA Research Foundation

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Document Details:

Date: May 2023
Status: Final

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1 Introduction

Overall, the crash record of older drivers compares well with other age-groups which indicates that they can generally negotiate the parts of the road network on which they feel comfortable, safely. Also, medical advances have improved the health status of older people, so on average, older drivers of today will be healthier than those of 20 years ago. This means that older literature related to older driver safety may apply to a different population than is on the road now. The car is a very important mobility source to older drivers and their passengers. Therefore, it is important to allow older drivers to better utilise this important mobility source, for themselves and their passengers. This means it would be good for more of the network, at more times of the day and year, to be within the safe comfort zone of older drivers. This will increase in importance over the next few decades because older age groups are projected to grow in numbers considerably, with the change in younger age groups being relatively small in comparison.

To achieve this may require changes to the road infrastructure. These changes are not major network redesigns, but more tweaks around the margins. In terms of signage, lighting, relatively minor infrastructure works, intersection design changes, signal phasing etc. The changes may need to be more widespread and over time, more expensive until a network more suited to all ages is achieved. This is because historically the standards used have been derived from experiments involving relatively young cohorts, making the age group for which they are designed relatively young. These areas include lighting, delineation, sight distances and signage and also changes to road street and intersection design. Up until now road network designers have been reluctant to consider such changes except in localised pockets of the network. It is important to note that changes aimed primarily to assist older drivers will also have a positive impact on drivers in other demographics and advance efforts to make our network more compliant with the principles of the safe system approach to road safety, summarised by Waka Kotahi (n.d.) as:

The safe system approach recognises that people make mistakes and are vulnerable in a crash. It reduces the price paid for a mistake so crashes don't result in loss of life or limb. Mistakes are inevitable – deaths and serious injuries from road crashes are not.

In fact, most infrastructural changes mentioned here will be mentioned elsewhere as changes which are needed to move towards Vision Zero

This report will look at the various ways older drivers (and by implication other drivers) can be assisted to travel our roads without serious injury or death occurring. It will look at general network measures, namely lighting, delineation and signage. These are very important due to their widespread application. It will then move on to more site-specific treatments which will include site specific applications of lighting, delineation and signage.

2 Lighting infrastructure

2.1 Introduction

It is important that road lighting does its job of allowing drivers to see obstacles (including pedestrians) in time for them to take evasive action to avoid a crash, This should apply to all age groups of drivers.

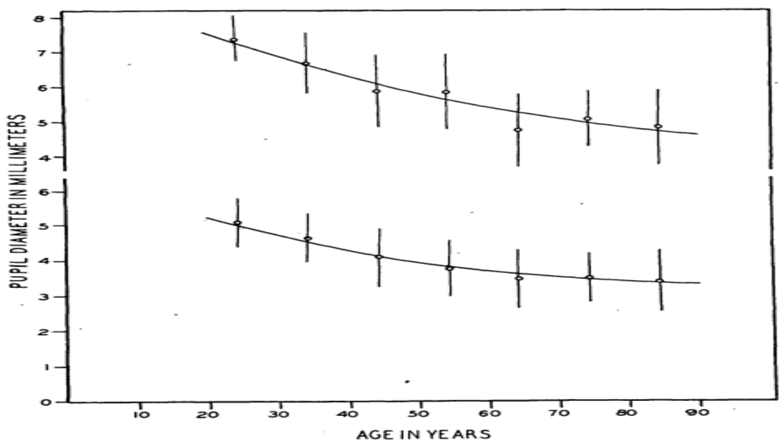
Replacement of High Pressure Sodium (HPS) streetlights with Light Emitting Diode (LED) streetlights has been happening around the world. This has been led by the superior energy efficiency of LED lighting, its greater longevity, its lower need for maintenance and its ability to be dimmed and strengthened according to varying temporal needs. Future choices relate to type of LED rather than whether LED or some other light source is used.

This has led to discussion around the impact of the change, particularly the greater proportion of blue light in the output of LEDs compared with the previous HPS lighting. Correlated Colour Temperature (CCT) is a rough guide to the percentage of blue light emitted by a source and it is generally agreed that streets should not be lit by lights of colour temperature above 4000K (Frith, 2021). Blue light is utilised less affectively by the eye as it ages. This relates to the pupil narrowing and the lens becoming cloudier.

2.2 Blue light loss related to narrowing of the pupil with age

The pupil of the eye narrows with age owing to weakening of the small muscles which serve to keep it open. It's changes with age are illustrated in Figure 2-1 from Birren et al (1950).

Figure 2-1:Mean pupil diameter (mm.) by decades of age.



The upper curve relates to pupil size in the dark with the lower relating to pupil size in one lumen of brightness. The lines are least squares regressions and the vertical lines represent ± one standard deviation. This narrowing reduces the amount of light reaching the lens and thus the amount reaching the retina. The pupil size varies with the wavelength of incident light. Daneault et al, (2012) looked at pupil constriction in 16 young (22.8 ± 4 years) and 14 older (61 ± 4.4 years) subjects with 45s exposures to blue (480 nm) and green (550 nm) monochromatic lights at low, medium, and high irradiance levels. Steady-state pupil constriction was greater under blue than green light in both age groups and increased with increasing irradiance.

2.3 Blue light loss by yellowing of the eye's lens

Blue light is lost by absorption through yellowing of the eye's lens (Van Bommel, 2015). The yellowing process is well underway by the time an individual reaches age 25. Barker and Brainard (1991) found that at 450 nm the transmittance of post-mortem lens of 60-69 year olds is half that of 20-29 year old adults. At 425 nm it is one third. Figure 2-2 illustrates the changes in the lens as it ages.

Figure 2-2: Changes in the lens of the human eye through ageing (Van Bommel, 2015)

Figure 2-3: goes a step further to illustrate the impact of age under 2700K LED and 4000K LED lights. The top left photograph simulates what a 25-year-old would see under LED lighting. The top right simulates what a 65 year old with pupil size reduced to 55% of the 25 year old's pupil would see if lens transmission were unchanged.. The bottom left shows what that 65 year old would see under 2700K LEDs and the bottom right what the 65 year old would see under 4000K LEDs given the different impact of lens clouding associated with 2077K and 4000K. LEDs.

Figure 2-3: the impact of age under 2700K LED and 4000K LED lights (Van Bommel, 2015)

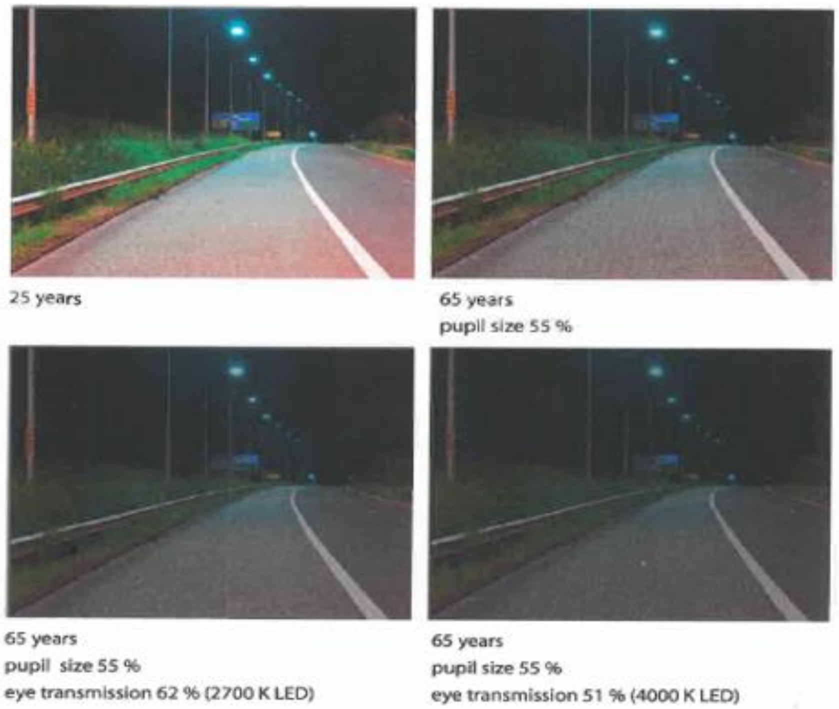


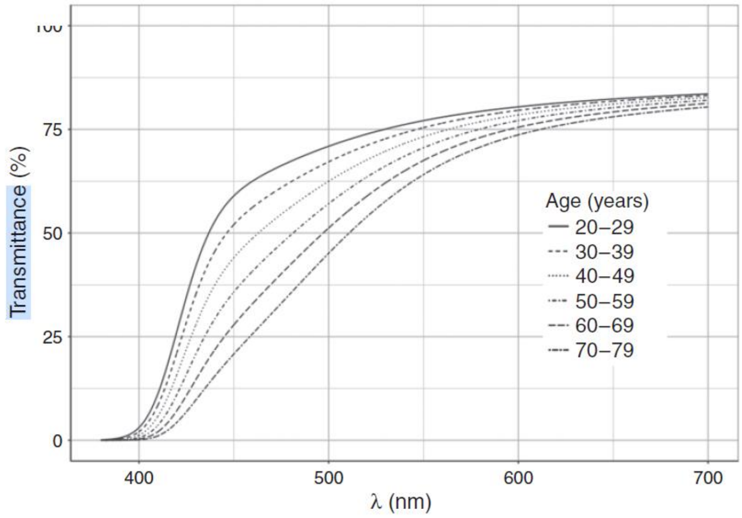
Table 2:1, also from Van Bommel (2015) quantifies the above for a 2700 LED and a 4000K LED comparing light transmission of a 25 year old with that of 50 and 60 year olds.

Table 2:1: Transmission of warm-white and cool-white LED light through the eye lenses of 50 and 65 year old people relative to that of a 25 year old.

	Transmission relative to 25 year old (%)	
Age	Warm-white LED 2700 K S/P ratio: 1.28	Cool-white LED 4000 K S/P ratio: 1.47
50	66	55
65	62	51

Table 2:1 shows that on average older people will receive more benefit per lumen from a typical 2700K LED than from a typical 4000K LED. This is related to the bluer spectrum of the 4000K LED. To illustrate, from Table 2:1, a 50 year old will receive 45% less light to the retina per lumen from a 4000K LED than a 25 year old and for a 2700K led the loss will be 34%. Preciado and Manzano (2018) went further by plotting the lens transmittance of various age groups against a baseline of 20 -29 year olds (Figure 2-4).This shows the relatively low transmission of the lower wavelengths of the blue light by all age groups particularly those who are older.

Figure 2-4: Human lens transmittance by age-group and wave-length (Van Bommel, 2015)



Preciado and Manzano (2018) have shown that at higher values of mesopic luminance around 0.9 CD/m^2 more light is necessary from the LED in order to gain the same impact on the retina as an HPS source owing to the higher blue light proportion, as discussed above, for both 40 year olds and 60 year olds[1]. This will be more so those older than 60 such as 70+ people. According to Ministry of Transport Travel (2015) survey results drivers 70+ travelled on average 1.7 billion kilometres per year in the 4-year period 2011-.2014 out of a total of 30.4 billion. This represents 5.6% of all kilometres travelled.

2.4 Adaptive LED lighting

LED lighting can be tailored to the demographics of road users in a particular area and changed depending on the current conditions using computer control systems

2.5 Takeaways

- Road lighting levels should be recalibrated so the older age-groups of drivers are acceptably catered for (e.g., using luminaires that produce a lower amount of blue light)
- The adaptive programming of LED lighting should be actively considered as a mechanism to assist older drivers (e.g., brighter from dusk to midnight, and lower after midnight when older driver crashes are lower to optimise both safety and energy use)

3 Delineation

3.1 Visibility of road markings

Road markings need to be visible to all age groups, far enough ahead for them to have adequate time to safely take the safety related actions required as a consequence of seeing the markings.

Night visibility of road marking is highly dependent on their retroreflectivity. According to Dravitzki et al (2006) non-reflectorised markings have reflectivities of about 75 mcd.m-2.Lux-1 when new, and deteriorate to about 35 mcd.m-2.Lux-1 over a six- to twelve-month period. Reflectorised markings have reflectivities of about 220 mcd.m-2.Lux-1 when new and deteriorate to the same value as the non-reflectorised markings over a 12 to 24 month period. However, most contracts require them to be replaced before they deteriorate to 70 mcd.m^{-2}.Lux^{-1}. Lines of

[1] These figures may require some discounting when applied to present day LEDs, which may have lower S/P ratios than the 2.41 quoted in the table, implying lower proportions of blue light.

similar retroreflectivity can provide different levels of visibility depending on several factors including the driver's age, the marking width, and the position of the marking on the road.

According to Dravitzki et al (2003) the ability of a driver to see delineation adequately is a function of its size, its position on the road, the illumination provided by daylight, streetlight or vehicle lights, the driver's vehicle type, the vehicle's speed and the driver's visual capabilities. Information on these items can be used to calculate the distance ahead that a driver, in a particular set of circumstances, will adequately see delineation. This is called the "*preview time*".

Studies show that easy, comfortable driving requires a preview time of five to ten seconds of the general route ahead. Research from Europe has established two seconds as an absolute minimum for preview of the lane immediately in front to allow for appropriate vehicle placement.

Figure 3-1 depicts edgeline preview time vs driver's age for 70mcd/75mm and 100mcd/100mm edgelines.

It is apparent that the preview time drops with driver age going below the 2 second minimum threshold in the early 70s for 70mcd.m^{-2}. Lux^{-1} reflectivity, 75mm wide edgelines and around age 80 for 100mcd.m^{-2}.Lux^{-1} reflectivity, 100mm wide edgelines. This means that simply making edgelines wider and brighter can increase the age at which the threshold is passed, by around 7 years. At the time of writing of Dravitzki et al (2003), most edgelines in New Zealand were 70mcd.m^{-2}.Lux^{-1} reflectivity, 75mm wide edgelines. Present Waka Kotahi (2010) Guidance states that 100mm width edgelines should be used.

Figure 3-1: Preview time v driver's age for 70mcd/75mm and 100mcd/100mm edgelines (100km/hr, high beam headlights) Dravitzki et al (2003)

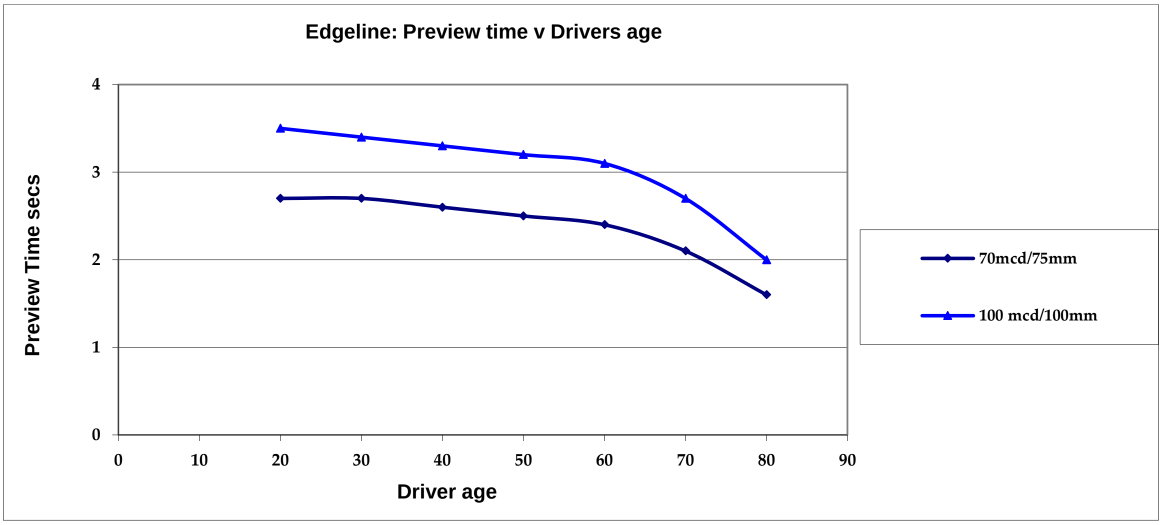


Figure 3-2: Combinations of line width and retroreflectivity level with equivalent levels of visibility for 70-year-old drivers Dravitzki et al (2003).

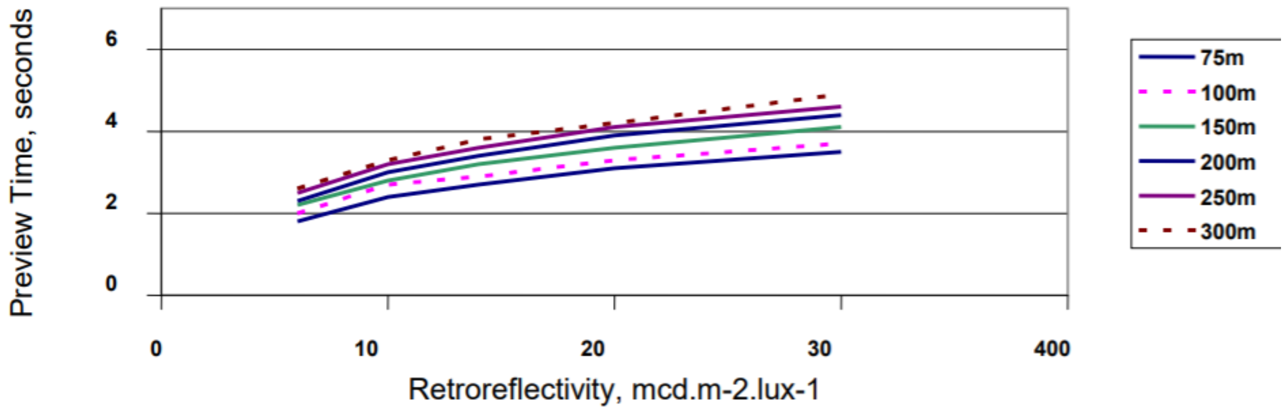
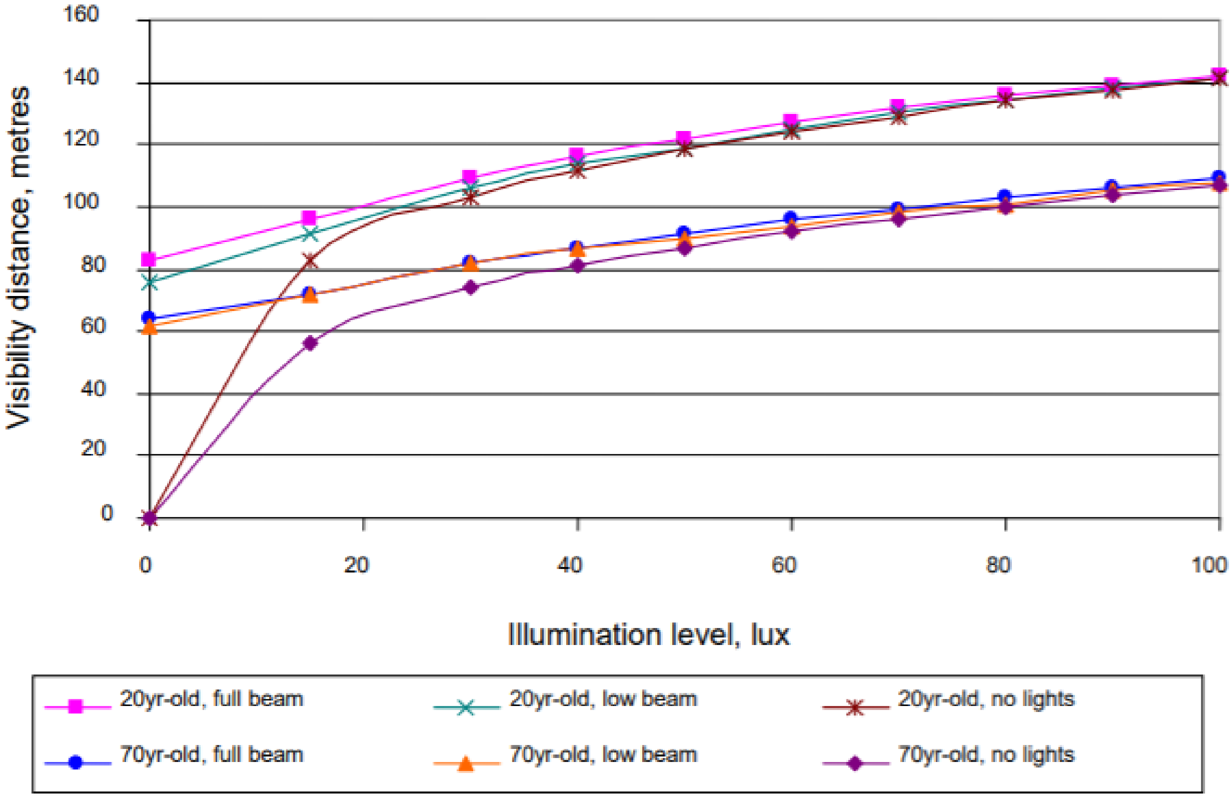


Figure 3-2 shows the preview times associated with a range of combinations of line width and retroreflectivity. Current New Zealand practice requires edgeline delineation in the bottom left-hand of this family of curves, both with respect to width (75 to 100mm) and reflectivity (50 to 150 mcd.m-2 .lux-1). Wide edgelines are either 150mm or 200mm wide can be used in both urban and rural areas at the discretion of the Road Controlling Authority.

Visibility distance, the distance away from the object at which it can be seen clearly, is the distance equivalent of preview time. Figure 3-3 depicts the impact of lighting level and headlight beam position on visibility distance of markings for 20yr olds and 70yr olds under street lighting, or at dusk. About 15-20 Lux is motorway standard, with most street lighting being about 2-5 Lux. Twilight is 30-100 Lux, and full sunlight about 10,000 Lux. With street lighting retroreflectivity becomes a small contributor to total visibility as the lighting level increased. The difference between the two curves “low beam” and “no lights” shows the contribution from retroreflectivity.

Figure 3-3: Impact of lighting level and headlight beam position on visibility distance of markings for 20yr olds and 70yr olds (Dravitzki et al, 2003)



The important part of this chart is that up to around 10 lus as 10 lux is a level seldom exceeded in road lighting.There is a relatively large difference between low and high beam at night for 70-year-olds. That difference becomes smaller and the no-vehicle lights condition approaches the lit conditions as night approaches twilight and the contribution of retroreflectivity lessens. At high lighting levels-(i.e., as twilight turns to day) even low grade markings become adequately visible.

Table 3:1 is taken from Dravitzki et al (2006). It depicts the forward viewing time at 100 km/h driving speed for reflectorised and non-reflectorised 100 mm edge lines for young drivers (15 to 35 years) and older drivers (65 to 75 years) on unlit roads. At 50 km/h the forward viewing time is doubled and the distance viewed stays the same.

Table 3:1; Visibility of new and old 100 mm edge line roadmarkings, expressed as seconds of forward viewing time when travelling at 100 km/h. .Dravitzki et al (2006).

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

It is apparent that:

- The viewing time reduces considerably between the old and new condition
- The viewing time is considerably higher when the lines are reflectorised
- Full beam gives better viewing time than low beam
- Older drivers receive a lower viewing time than younger drivers.
- Slowing down is a good way to increase forward viewing time.

Table 3:2. Is similar to Table 3:1 but looks at the midpoint between the new and old condition. The rationale for this table is that much of a marking's service life is covered by a plateau in the deterioration profile where performance is reduced but final deterioration has not been reached. Assuming this condition is represented by the mid-point, reflectorisation improves viewing time by about 0.5 to 1.0 seconds, or 20 to 40% with older drivers only being over the absolute minimum 2 second threshold on full beam when markings are not reflectorised,. Reflectorised marking exceed the 2 second threshold for all ages and for both full beam and low beam (Dravitzki et al, 2006).

Table 3:2: Visibility of 100 mm edge line roadmarkings in typical in-service condition, expressed as seconds of forward viewing time when travelling at 100 km/h. Dravitzki et al (2006).

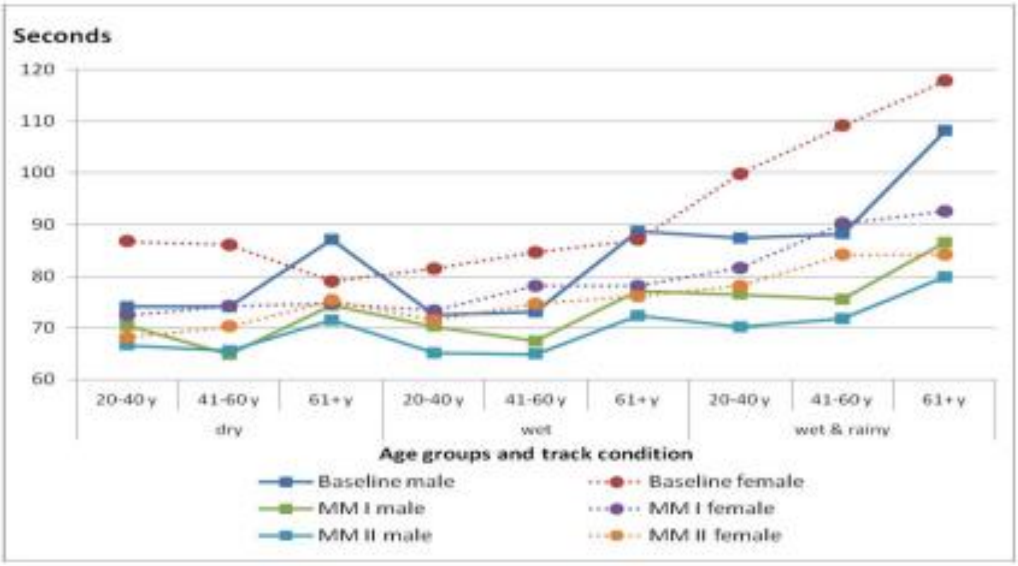
Driver age	**Visibility of markings in typical in-service condition (seconds)**			
	Non-reflectorised marking		Reflectorised marking	
	Dipped	Full beam	Dipped	Full beam
Young driver	2.3	2.6	3.0	3.7
Older driver	1.7	1.9	2.4	2.9

3.2 Wet markings

The usual painted pavement markings are often hard to see in wet conditions. This is because the reflectivity is produced by glass beads in the paint. When rain is hard enough to cover the markings the water mimics an optical lens by changing the refraction of light so that it is no longer returned to the driver.

This makes the driving task to be more difficult. (Milling & Tripahi, 2017). This is an obvious concern for all drivers including older driver. This problem can be alleviated by the use of markings which prevent this film of water forming. There are many such markings. An example is that used in Diamandouros and Gatscha, (2016) where a non-reflective marking is compared with a reflective marking (negligible wet visibility- 3–12 mcd/m^2 lx) and another reflective marking with acceptable (43–112 mcd/m^2 lx) wet visibility. Diamandouros and Gatscha, (2016) describe a project which included a test-track trial of the 3 types of marking. The subjects, who covered a range of ages, drove under three different driving conditions: (dry, wet and wet & rainy). The speed behaviour of the drivers in the various age and gender groups under the three conditions is depicted in Figure 3-4. Three age groups were analysed; 20–40 years, 41–60 years and 61+ years old drivers, both male and female. It was found that drivers drove faster in dry conditions and drove faster in wet conditions when the markings more visible. The speed of travel in wet conditions reduced with driver age but was faster with the more visible wet marking including the older group of drivers. This all indicated that the visible markings made travel more comfortable and somewhat faster under wet conditions. The increase in speed was not considered hazardous as it was accompanied by a compensatory increase in preview time.

Figure 3-4: Mean lap times for different age groups and marking conditions by gender- (Diamandouros & Gatscha,2016).



Profiled markings which include Audio Tactile Pavement Markings (ATPMs) and high performance pavement markings are the best choice in New Zealand for visibility as they sit proud of the roads surface above water layers and thus largely nullify the impact of wetness on visibility. These markings also have other advantages for older drivers through the audio tactile properties of ATPMs and some high-performance markings.

3.2.1 Other delineation devices

Road markings in the form of lines are not the only delineation devices. There are also other devices like raised pavement markers (RPMs) post mounted delineators, reboundable posts associated with road works and such things as markers placed on poles the ends of barriers etc. and chevrons. These should also be set up in the first place to provide acceptable visibility distance for all ages and be maintained to keep these acceptable through their lifetimes.

3.3 Takeaways

- Preview times should be at least two seconds under all circumstances.
- Reflectorised markings should be the norm
- At least 100mm wide reflectorised edgelines and centrelines should be used.
- Road Controlling Authority actively consider wider edgelines and centrelines that are either 150mm or 200mm wide.
- Excellent maintenance is of high importance.
- All age groups benefit from road markings which are visible in wet and rainy conditions. Profiled markings have advantages to older drivers owing to their superior visibility in wet weather
- High beam visibility is better than low beam visibility, implying that headlights should be on high beam whenever legal. The difference between low-beam visibility and high beam visibility in the dark increases with driver age. This indicates that auto high beam vehicles should be the vehicle of choice for older drivers.

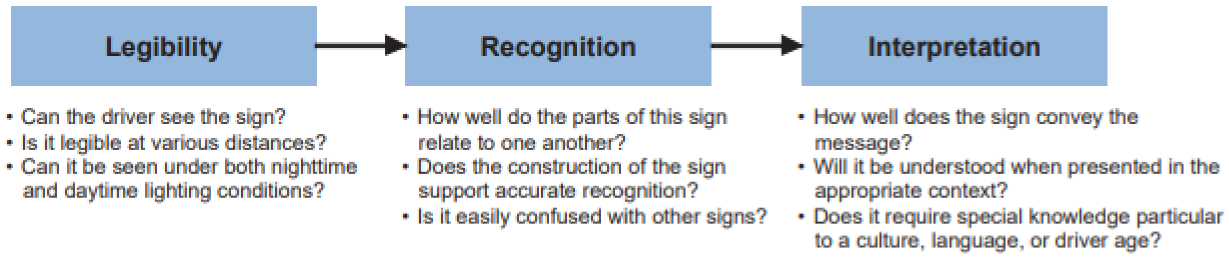
4 Road sign effectiveness

4.1 Introduction

It is important that the messages on road signs are fully comprehensible by all ages at distance where they can take the actions required to comply with the messages. The diagram in Figure

4-1 from NCHRP (2010) quoting Campbell et al (2003) describes the sequence of three stages associated with comprehension and use of signs.

Figure 4-1: The three stages associated with comprehension and use of signs: (NCHRP, 2010)



4.2 Legibility of road signs

This is very important as it is the first stage of the process in signs: Legibility includes the legibility of symbols as well as text. NCHRP (2010) lists the following specific points to remember when designing with older drivers in mind.

- Minimize symbol complexity by using very few details.
- Maximize the distance between symbol sign elements.
- Use representational rather than abstract symbols
- Use solid rather than outline figures for design.
- Standardize the design of arrowheads, human figures, and vehicles.
- Retain maximum contrast between the symbol and the sign
- background.
- Use a larger font when possible.

4.3 Symbols vs words

The consensus of the literature is that where possible symbols should be used rather than words. For example, Kline et al (1990) compared the visibility distances for young, middle-aged, and older observers of text and symbolic versions of four different highway signs under day and dusk conditions. They found the symbolic signs had much greater visibility distances than the text signs for all age groups with the difference being more pronounced at dusk. No age differences were detected in the comprehension of symbolic signs, but different symbolic signs differed in their comprehensibility, icon signs appeared to offer all drivers almost twice as much time in to respond than text signs.

4.4 Where words are required- Fonts- and font size.

Both letter size and font type are considerations for sign legibility for older drivers. The Waka Kotahi (2008) TCD manual states that:

It is also important to recognise that a larger letter size is likely to improve legibility for older drivers.

The Austroads Guide to Traffic Management (GTM) Part 10 recommends that:

at locations where the background and surroundings to the sign have a large amount of material that would make the sign difficult to see (e.g., urban areas with illuminated advertising signs, shop fronts or other lights), a larger legend and sign may be used at the discretion of the designer.

New Zealand traffic sign fonts are based on Highway Gothic, a font developed in the 1940s by the US Federal Highways Administration designed to be easily read at speed on highways. There is also another font called Clearview. Clearview is an option in the US which some consider superior to highway gothic, but the evidence for this superiority is unclear. This means that evidence for any change in font to improve signs for older drivers is lacking. Font size should be as large as possible given the circumstances of the sign to give the driver as much preview time as possible.

Mace et al (1994) quoted in Smiley et al (2008) also found that increasing letter height had a less than proportionate impact on legibility.

4.5 Comprehension and legibility of symbolic signs

There is evidence that older drivers can have more difficulty comprehending some symbolic signs than younger drivers. Figure 4-2 depicts the legibility distances for five types of symbolic sign (Warning, School, Guide, Regulatory, and Recreation/ Cultural). The drivers in a US laboratory based experiment were divided into three age ranges: young (6 men and 6 women aged 20 to 31), middle-aged, (6 men and 6 women aged 42 to 59), and older; (9 men and 9 women aged. 60 to 76). The older group was oversampled due to its known variability of performance. The following results were obtained.

4.5.1 Daytime legibility

The legibility distance (Figure 4-2) reduces with age for all sign types and is longest for warning. Regulatory is surprisingly in fifth place.

Figure 4-2: Daytime legibility distance of five symbolic sign types

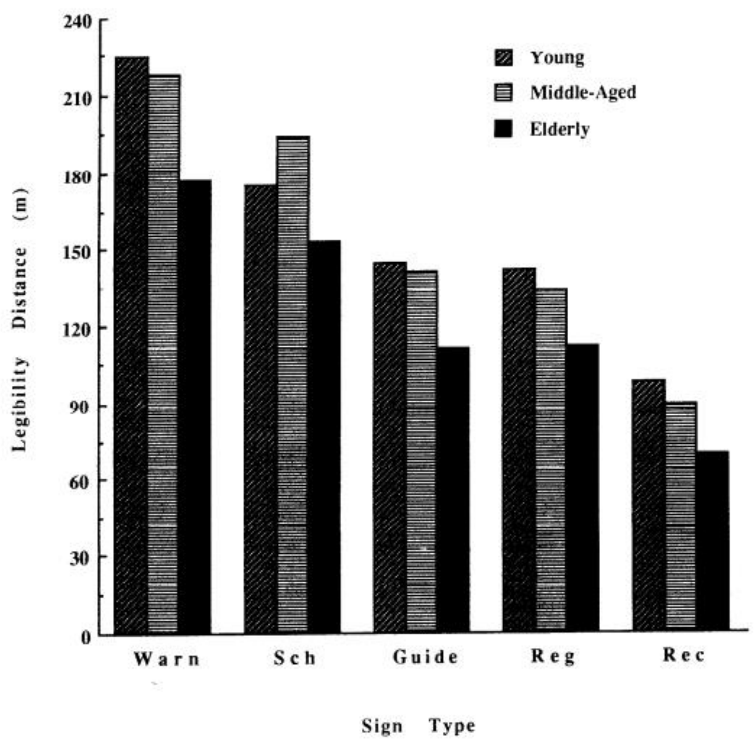


Figure 4-3:Comprehension of 5 symbolic sign types

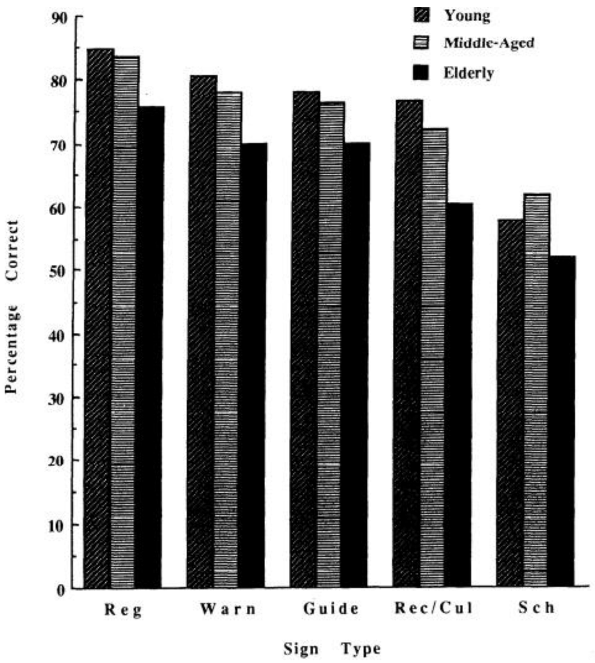


Figure 4-3 is a similar chart related to comprehension of the sign's messages. In this case warning and regulatory head the line-up. This indicates that good legibility does not automatically mean good comprehension. In both Figure 4-4 and Figure 4-5 older drivers followed the same general pattern as other age-groups but at a generally lower level. This indicates that the problems faced by older drivers are similar to those faced by the other groups, but that they occur at lower levels. In general, an inverse relationship was found between the number of small complex features on a symbol sign and the distance at which it is legible.

4.5.2 Night-time legibility

Figure 4-4 and Figure 4-5 depict night-time visibility distances with and without peripheral glare. The familiar drop off with age is observed with shorter distances in the presence of glare with the best signs considerably better than the less optimal ones.

Figure 4-4:Mean night-time legibility distances of different sign types as a function of driver age:

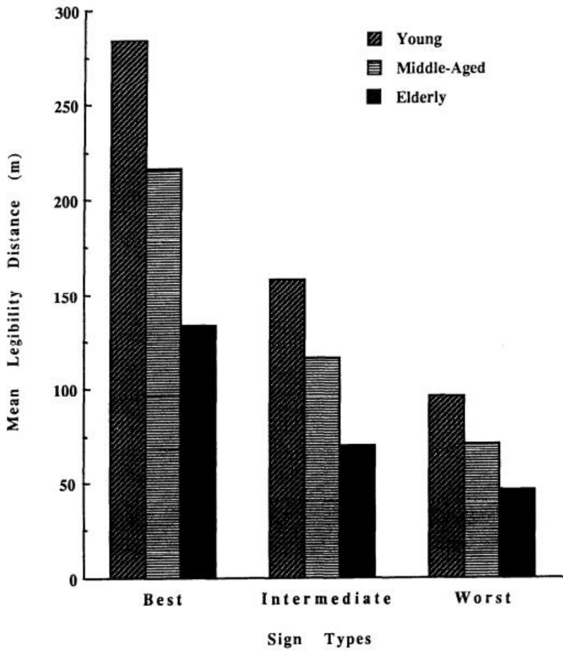
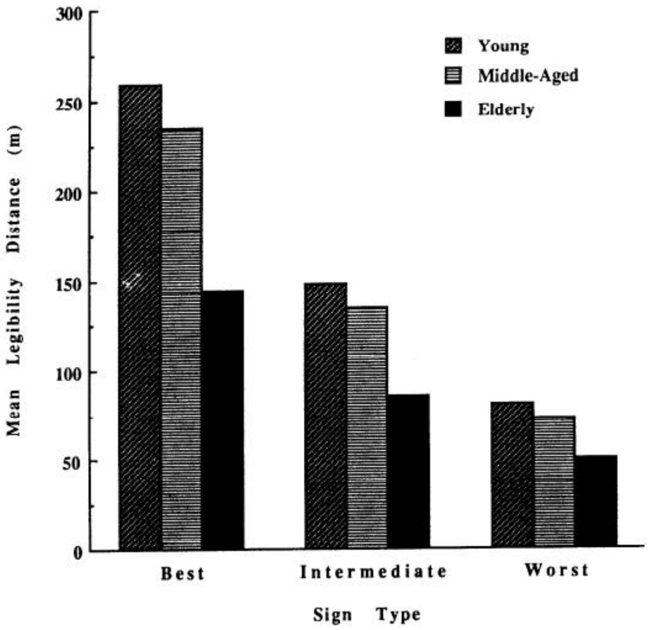


Figure 4-5:Mean night-time legibility distances of sign types as a function of driver age -with peripheral glare.



4.6 Dusk

Dusk, like glare is a low contrast condition and older drivers find low contrast increases difficulty. Kline, et al (1990) compared the legibility distances of text and symbol highway signs young, middle-aged, and older observers under day and dusk conditions. Symbol signs were visible from approximately twice as far away as text signs for all three age groups. This difference was greater at dusk. Older drivers, in common with their younger counterparts should also make sure that their headlights are deployed at the beginning of dusk.

4.7 Retroreflectivity

It is important for road signs to have acceptable retroreflectivity for all drivers so that they can be adequately viewed at night. – The Federal Highway Administration(FHWA)(2012) in the United

States prescribes minimum standards for retroreflectivity of sign material. In New Zealand Waka Kotahi (2008) has no such standards in its Traffic control devices (TCD) manual, part 1, general requirements for traffic signs. Instead it prefers to let road controlling authorities to set their own requirements, tailored to the particular situation where the sign is placed. It also recommends in M24 a drive by inspection regime to determine whether the sign is adequately visible to a human observer. Such drive by inspections are also recommended with regard to daytime visibility where any requirements for fluorescence are included. This amounts to a performance-based approach. This sort of approach provides inspection throughout the life of the sign thus being able to pick up degradation of the sign's material over time and recommend the replacement of substandard signs,

In the United States the inspections are set up to find and replace or clean those signs which do not comply with the US minimum retroreflectivity standard (Department of Transport, 2009). In the US these inspections are also recommended to be carried out by observers at least 60 years of age to presumably ensure that the signs are adequate for older road users. Such a provision could be considered in New Zealand.

4.8 Takeaways

- Symbolic signs should be used wherever possible, the simpler the better.
- Preview times should be at least two seconds under all circumstances
- For signs using text, font size should be as large as possible given the circumstances of the sign to give the driver as much preview time as possible
- Retroreflectivity of signs is based on performance in New Zealand as assessed visually by mobile inspectors. Having inspectors of over 60 years of age where possible should be considered as it would improve recognition of the requirements of older drivers

5 Specific infrastructure treatments

Appendix A lists in tabular form specific infrastructure treatments aimed at improving older driver safety. In most, if not all cases these treatments would improve safety for all drivers. These treatments generally target well researched areas where improvement would have safety benefits for older drivers. The treatments are designed to consider the effects caused by aging, including declining vision, reduced mobility, and changes in perception and cognitive functions. Some of these issues have already been discussed in sections 2, 3 and ▯ of this report. Several of these areas involve making the gap acceptance process easier for older drivers by reducing speeds and the number of separate traffic movements they must contend with at once, in some cases down to zero as with protected right turns at traffic signals. The above well researched areas provide the following takeaways.

5.1 Takeaways

- At intersections choosing the right type of control

  In many instances well-designed roundabouts with their slower speeds are better than signals or stop/give way control for older drivers

- Separate right turn phase where traffic volumes make turning right difficult
- Older driver appropriate entry sight distances at intersections
- Older driver appropriate right turn sight distances at intersections
- Upstream "intersection ahead" signage with acceptable preview time

- At signals, separate right turn phases where traffic volumes make turning right difficult.
- Traffic signal lanterns with enough power to ensure acceptable visibility for older drivers
- Appropriate channelisation, markings and signage to direct older drivers into their correct lanes
- More T-junctions, fewer crossroads -to reduce decision making complexity at intersections (for example, changing a crossroad into two T-junctions)

6 Temporary Traffic Management (TTM) treatments

6.1 Introduction

TTM has special relevance to older driver safety as in the words of FHWA (2014, pp 77):

Highway construction and maintenance zones deserve special consideration with respect to aging driver needs because of their strong potential to violate driver expectancy.

The following set of PIARC principles for *"safe, efficient and effective management of road work zones"* are especially applicable in the case of older drivers

- Conspicuous – this implies that the driver must be physically able to see what is coming up. The work zone must be obvious, noticeable and eye-catching to draw the attention of the drivers and encourage them to act in the desired way with regard to increased attention, speed adaptation and position of vehicle.

- Clear – which means that all signing, guiding and other instructions through road works must be clear for drivers so they can be absolutely certain about what is required in terms of correct decisions about how to safely approach and pass the site.

- Consistent – which implies that drivers should encounter uniform standards, layouts and arrangements at all work zone sites of the same kind, so they are conditioned to act in a certain expected way.

- Credible- means that the instructions are 'believable' so the drivers can rely on what they are told (e.g., the need to slow down) and that the messages they are given are a true representation of what will occur ahead.

Appendix B contains tables summarising a range of different treatments that can be used to ease the safe passage of older drivers when TTM is being implemented.

6.2 Takeaways

TTM must give ample warning to drivers of :

- *what lies ahead*
- *its location*
- *what they need to do in response.*

All markings, signing, and channelization must provide conspicuous, clear, consistent and unambiguous guidance (see Appendix B for specific treatment examples).

7 Vehicle issues

7.1 General vehicle safety

Rightcar[2] is Waka Kotahi"s web based system for imparting information on the safety of vehicles on the market , both new and used. Given their fragility, it is important that older people when they buy cars, buy the safest vehicles that they can afford. It is thus important that RightCar be well publicised to that age -group. Vehicle safety information from Rightcar is also provided to vehicle buyers at many dealerships. Older people need to be encouraged to make sure they have this information before buying a car.

7.2 Vehicle Fit

It is important that a vehicle driven by an older person fits them well ergonomically. This is because comfortably fitting a vehicle can help prevent physical problems which may require intervention from the medical profession or physiotherapists and also reduce the impact on safety of driver fatigue.

7.3 Use of ad hoc devices

Older people also need to be aware of problems with the ad hoc use of devices such as unanchored cushions to adjust the seating positions of drivers and passengers[3]. An unanchored cushion can cause chest injuries and can slide out from under a passenger facilitating submarining[4] out from a seatbelt in a crash. Adjusting the seat in accordance with the car's manual is the best method of improving comfort.

7.4 Disabled older drivers

There are several different types of vehicles being produced in Japan by several manufacturers for disabled drivers and passengers. These include such standard features as:

- Horizontally swivelling seats to facilitate entry to the vehicle
- Passenger and driver seats which can come and go from the vehicle and transform to electric wheelchairs outside the vehicle

Toyota has a line of such vehicles called "Welcab" vehicles[5].It is possible to order from Toyota in Japan bespoke Welcab vehicles tailored to the owner's needs. Japanese disability vehicles are available in New Zealand as used imports from specialist importers and other used car dealers. Figure 7-1 depicts a Welcab vehicle imported by Rod Milner Motors of Auckland which allows drivers to enter and exit the vehicle in their seat via the passenger door.

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[2] https://rightcar.govt.nz/
[3] https://www.neura.edu.au/news/older-driver-safety-compromised-by-seat-cushions-and-pillows/
[4] This refers to a vehicle occupant slipping out forwards from under their seatbelt due to a lack of friction between them and the vehicle's seat.
[5] https://toyota.jp/welcab/

Importantly, this means they exit directly onto the sidewalk rather than onto the road. The seat then becomes an electric wheelchair until the driver wishes to re-enter the vehicle.

Figure 7-1: 2008 Toyota Porte vehicle with entrance and exit via a portable driver's seat.(Image reprinted from https://www.rodmilner.co.nz/)

7.5 Advanced Driver Assistance Systems (ADAS)

Polders et al (2015) is the final report of a European Commission project on older road user safety. It found that ADAS has the potential to enhance older driver safety by assisting those with age-related deficits to compensate for them. Currently these systems are not designed with these people in mind and this should be remedied.

Among the recommendations are (in paraphrase):

- Systematically assess the usability and effectiveness of ADAS for older people by including their safety in NCAP testing.
- Educate and train older people on the correct usage of ADAS
- Encourage the further development of crash avoidance systems, such as intersection and lane change assistants and active pedestrian protection systems.
- Explore the potential benefits and drawbacks of (semi-) automated driving in extending the driving life of older drivers by assistance in compensating for possible functional limitations

It discusses ADAS as it pertains to older drivers under the headings:

7.5.1 Intersection

This requires sensors with a very wide field of view, a long range and a very good understanding of intersection geometry. The first generation of such systems addresses. simple scenarios, using sensors such as a camera and/or a navigation system., For instance the driver may be warned on approaching a red traffic signal stop sign, or a crossing pedestrian. The next generation requires car to car (Car2car) and between vehicle and infrastructure (Car2x) communication.

Work related to five different intersection assistance systems was investigated. The systems were tested on "Younger older drivers mainly below 80 years of age". The systems were described as:

- *A support system to prevent left-turn collisions and collisions with crossing pedestrians (Daimon & Kawashima, 2003);*

- *An advanced in vehicle information system using a head-up display format (Caird, Chisholm, & Lockhart 2008). They evaluated two visual forms of safety messages: "prepare to stop" (a traffic light inside a rectangle) and "signals ahead" (a traffic light inside a diamond);*

- *A time gap assistant system using a head-up display (Gelau, Sirek & Dahmen-Zimmer, 2011);*

- *A device mounted in the high centre position of the dashboard which provided an in-vehicle message to select a gap for left turn(right turn in NZ) across path / opposite direction (LTAP/OD) manoeuvres (Bougler et al., 2005);*

- *A simulated driver assistance system that provides prior knowledge on the next traffic situation by informing the driver about one of four aspects of that particular situation (Davidse, 2006):*
    1. *whether the driver has right of way,*
    2. *whether it is safe to join or cross traffic,*
    3. *whether the driver will have a good view of crossing traffic, and*
    4. *whether there are any deviating traffic rules or road situations (e.g., different speed limit or one-way street).*

The major results were:

- Information provision by all systems was proven to be effective.
- No negative effects on safety were found.
- Improved stopping accuracy,
- shorter accepted safe time gaps,
- a 10% reduction of accepted unsafe time gaps or distance between vehicles,
- a reduction in speeds at intersections,
- safer decision making- fewer route-errors and deceleration manoeuvres of other drivers with right of way.
- When advanced warning signs were provided, drivers were 2 times more likely to stop at the intersection compared to the baseline scenario.
- The accepted time gap was reduced to 1.5s for older drivers
- Drivers were 5 times more likely to anticipate a traffic light change when the advanced warning sign was displayed compared to the baseline drivers (Caird, Chisholm, & Lockhart 2008).
- Older drivers looked at the heads up display significantly less than younger drivers

Overall, the measures were judged to improve safety at intersections by permitting safer decisions. They may reduce stress and anxiety and thus any propensity to make inappropriate decisions under time pressure from road users. Roessler, Westhoff, & Sick, 2010 estimates a gain of 40% for injured people and 20% for fatally injured people in Europe.

7.5.2 Headway control

The following three systems were looked at.

Adaptive cruise control (ACC):

this system maintains a set speed and, when applicable, adjusts the speed to maintain a specified distance from a lead vehicle. (Jenness et al., 2008) "Younger and "very old" older drivers

Forward crash warning (FCW):

is an in-vehicle electronic system that monitors the roadway in front of the host vehicle and warns the driver when a potential collision risk exists. (This has now been augmented into forward crash mitigation where a brake can be automatically applied to mitigate or prevent if possible a collision) (Nodine et al., 2011) "Young" older drivers

Headway detection and alerting device (HDAD)

Detects the Time Headway (TH) of the driver's car to the lead vehicle and sounds an alert if it falls below a set value.. (Maltz et al., 2004)."Young" older drivers.

It was judged that

- Older drivers maintained a more constant driving speed and headway when using the systems.
- Older drivers reduced headways and could increase speeds. However, the headway remains within a safe range
- A "safe" range (>2s.) was maintained under distraction.
- Drivers responded to forward threats more quickly when they received FCW alerts
- Overall, the devices were well accepted by older drivers

Overall, the impact on older driver safety was positive with a caution that hearing ability can decreases with age so systems that rely on audio messages need to take this into account. This situation is less important than some others as rear end crashes are one of the less frequent types of crashes for older drivers.

7.5.3 Lateral control

These systems assist the driver in case of lateral displacement. The following systems were looked at:

Lane Departure Warning (LDW) (Visvikis, Smith, Pitcher, & Smith, 2008)

This warns the driver if the vehicle deviates laterally from its lane

Lane Keeping Assist (LKA)

This slightly turns the steering wheel to keep the vehicle in its lane (Visvikis et al., 2008)

The Lane Centring Assist

This helps the driver to keep the vehicle centred in its lane, by applying a light steering torque. (Visvikis et al., 2008)

Blind Spot Detection system (BSD) (Visvikis et al., 2008)

This warns the driver when a vehicle is in its blind spot,

Lane Change Assist (LCA) (Visvikis et al., 2008)

This warns the driver if they intend to change lanes when a vehicle is approaching from the rear in the next lane

It was judged that:

- Older drivers (60-70 years old) maintain a better lane position with fewer lane deviation (21% decrease), with cautionary and imminent lane departure alert

- In case of a conflict during a lane change to the left, the lane incursion time decreases significantly. The ADAS tested has no effect on lane deviation duration.
- lane change/merge near-crash rates did not decrease for older drivers.
- Older drivers report usefulness, effectiveness, an increase in their driving safety, and in their awareness.
- Lane change/merge warning or blind spot monitoring have a minor impact on safety,
- Blind spot monitoring is viewed as a comfort system by older drivers.

They conclude that of all the systems, these systems are the most beneficial to older drivers.

7.5.4 Curve control

The major ADAS system applying here is Vehicle Stability Control (VSC) also called Electronic Stability Control (ESC). This has a well attested safety impact over all crashes and less of an impact on older driver crashes as their tendency to caution reduces the chances of it deploying

7.5.5 Navigation

There is little hard evidence around the impact of navigation systems on older driver safety. Polders et al (2015) recommend simplifying the ergonomics of the navigation system and makes the point that navigation systems do not address older driver safety directly but could impact it indirectly by improving driver confidence to visit certain areas (Jenness et al., 2008).

7.5.6 Parking

Park assist uses sensors in conjunction with camera(s) to assist a driver to enter and exit a parking space. As crashes of these types are generally damage only the safety impact is low except in the case of rear pedestrian detection.

7.5.7 Night driving

Older drivers tend to do limited night driving. Night Vision systems allow the driver to see better at night and thus more effectively react to danger and auto high beam automatically detects when low and high beam should be used and changes accordingly. These enhancements have face validity as safety enhancers for older drivers, but research evidence is scarce.

7.5.8 Driver monitoring

These technologies which might monitor drowsiness and warn of impending medical incidents are still underdeveloped

7.5.9 Autonomous Vehicles

Fully autonomous vehicles, which achieve fully safe operation would benefit older drivers, as they would all road users. Vehicles with autonomous characteristics come in 6 levels of automation (Society of Automobile Engineers., 2014). Where automation is partial, meaning driver intervention will be required in certain circumstances, these vehicles should be set up with the older driver in mind with respect to intervention requirements.

7.6 Takeaways

7.6.1 General issues

- The Rightcar website should be strongly marketed to older drivers
- Older drivers should be discouraged from using ad hoc devices like unanchored cushions as comfort or disability aids as they can cause submarining from seatbelts.

- Special vehicles with features for disabled drivers are available and should be brought to potential users' attention

7.6.2 Advanced driver assistance

7.6.2.1 Intersections

ADAS systems have excellent potential benefits for older drivers, but these do not in any way obviate the need for excellent intersection design.

7.6.2.2 Headway control

Overall, the impact on older driver safety was positive with a caution that hearing ability can decreases with age so systems that rely on audio messages need to take this into account. This situation is less important than some others as rear end crashes are one of the less frequent types of crashes for older drivers.

7.6.2.3 lateral control

Of all the systems, these systems are considered the most beneficial to older drivers.

7.6.2.4 Auto high beam

High beam is always better than low beam when conditions allow its use. Auto high beam automatically detects when low and high beam should be used and changes accordingly

8 Summary of takeaways

8.1 Lighting infrastructure

- Road lighting levels should be recalibrated so the older age-groups of drivers are acceptably catered for (e.g. using luminaires that produce a lower amount of blue light)
- The adaptive programming of LED lighting should be actively considered as a mechanism to assist older drivers (e.g. brighter from dusk to midnight, and lower after midnight when older driver crashes are lower to optimise both safety and energy use)

8.2 Delineation

- Preview times should be at least two seconds under all circumstances.
- Reflectorised markings should be the norm
- At least 100mm wide reflectorised edgelines and centrelines should be used.
- Road Controlling Authority actively consider wider edgelines and centrelines that are either 150mm or 200mm wide.
- Excellent maintenance is of high importance.
- All age groups benefit from road markings which are visible in wet and rainy conditions. Profiled markings have advantages to older drivers owing to their superior visibility in wet weather
- High beam visibility is better than low beam visibility, implying that headlights should be on high beam whenever legal. The difference between low-beam visibility and high-beam visibility in the dark increases with driver age. This indicates that auto high beam vehicles should be the vehicle of choice for older drivers.

8.3 Road sign effectiveness

- Symbolic signs should be used wherever possible, the simpler the better.
- Preview times should be at least two seconds under all circumstances

- For signs using text, font size should be as large as possible given the circumstances of the sign to give the driver as much preview time as possible
- Retroreflectivity of signs is based on performance in New Zealand as assessed visually by mobile inspectors. Having inspectors of over 60 years of age where possible should be considered as it would improve recognition of the requirements of older drivers

8.4 Specific infrastructure treatments

- At intersections choosing the right type of control

  In many instances well-designed roundabouts with their slower speeds are better than signals or stop/give way control for older drivers
- Separate right turn phase where traffic volumes make turning right difficult
- Older driver appropriate entry sight distances at intersections
- Older driver appropriate right turn sight distances at intersections
- Upstream "intersection ahead" signage with acceptable preview time
- At signals, separate right turn phases where traffic volumes make turning right difficult.
- Traffic signal lanterns with enough power to ensure acceptable visibility for older drivers
- Appropriate channelisation, markings and signage to direct older drivers into their correct lanes
- More T-junctions, fewer crossroads -to reduce decision making complexity at intersections (for example, changing a crossroad into two T-junctions)

8.5 TTM

TTM must give ample warning to drivers of:

- *what lies ahead*
- *its location*
- *what they need to do in response.*

All markings, signing, and channelization must provide conspicuous, clear, consistent and unambiguous guidance (see Appendix B for specific treatment examples).

8.6 Vehicle issues

8.6.1 General issues

- The Rightcar website should be strongly marketed to older drivers
- Older drivers should be discouraged from using ad hoc devices like unanchored cushions as comfort or disability aids as they can cause submarining from seatbelts.
- Special vehicles with features for disabled drivers are available and should be brought to potential users' attention

8.6.2 Advanced driver assistance

8.6.2.1 Intersections

ADAS systems have excellent potential benefits for older drivers, but these do not in any way obviate the need for excellent intersection design.

8.6.2.2 Headway control

Overall, the impact on older driver safety was positive with a caution that hearing ability can decreases with age so systems that rely on audio messages need to take this into account. This situation is less important than some others as rear end crashes are one of the less frequent types of crashes for older drivers.

8.6.2.3 lateral control

Of all the systems, these systems are considered the most beneficial to older drivers.

8.6.2.4 Auto high beam

High beam is always better than low beam when conditions allow its use. Auto high beam automatically detects when low and high beam should be used and changes accordingly.

9 Conclusions

- ADAS systems in vehicles are not at present put together with older drivers in mind, and this should be rectified.
- New Zealand, along with other developed countries generally lags behind what is required in terms of infrastructure to make our roads safer and more friendly to the needs of a growing group of older drivers.
- In large part this comes down to the research on which our practices are based being carried out using younger people as subjects.
- Revised practices, taking more into account the needs of older drivers are recommended.
- The interface between road infrastructure and advanced vehicle features also needs improvement if older drivers are to maker best use of these features.

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Appendix A-Infrastructure treatments

The following are some specific iinfrastructure treatments mentioned in the literature.

Intersection treatments

Treatment	Summary of treatment	References
Intersection angle	The preferred angle for intersections is right-angle. Decreasing the angle makes detection of and judgements about potential conflicting vehicles more difficult, as well as increasing the time it takes to manoeuvre through the intersection.	Austroads, 2004, p. 148 European Commission, 2015, p. 94 U.S. Department of Transportation FHWA, 2014, pp. 19, 96
Intersection receiving lane width	Receiving lanes should be wide enough to allow for correct lane positioning upon completing a manoeuvre through an intersection. Narrower receiving lanes can result in greater encroachment in the opposing lane. However, the lane width should not be so wide as to make it difficult for pedestrians to cross safely.	Austroads, 2004, p. 157 U.S. Department of Transportation FHWA, klingggg, pp. 20, 99
Intersection channelisation	Raised channelisation with sloping kerbs is recommended over pavement markings alone to increase detection of downstream geometric features (such as pavement width transitions and turning lanes).	Austroads, 2004, p. 161 European Commission, 2015, p. 96 U.S. Department of Transportation FHWA, 2014, pp. 20, 102
Intersection features to prevent wrong right-turn lane use	As well as channelisation, additional features can be installed to prevent the wrong lane use after a right-turn at a complex intersection. These features include lane use control signs, arrow markers, pavement markings, and delineation of median noises. Signs can also be used to prevent the use of the wrong lane where a major road with a median intersects a minor road.	Austroads, 2004, pp. 164, 184
Intersection sight distance	A driver approaching an intersection should have an acceptable sight distance of the entire intersection (including traffic control devices and lengths along the intersecting roadway) to allow them to identify and avoid potential collisions.	Austroads, 2004, p. 151 CAA, 2008, p. 24 European Commission, 2015, p. 95 U.S. Department of Transportation FHWA, 2014, pp. 22, 107
Intersection right-turn lanes offset	Positively offsetting opposing right-turn lanes improves the sight distance for the right-turning driver. Without an offset, vehicles in the opposing right-turn lane may fully or partially block visibility of oncoming traffic.	Austroads, 2004, p. 154 U.S. Department of Transportation FHWA, 2014, pp. 23, 122
Intersection right-turn sight distance	Right-turns at an intersection have a high probability of conflict between vehicles. To minimise this, acceptable sight distances that incorporate longer driver perception-reaction times should be considered.	Austroads, 2004, p. 154 CAA, 2008, p. 24
Intersection edge line and kerb delineation	Providing clear edge delineation of intersection features such as kerbs,	Austroads, 2004, pp. 166, 168, 170

	medians, and obstacles to make them more conspicuous at a distance helps drivers choose the correct lane and avoid collisions with raised surfaces.	European Commission, 2015, p. 96 U.S. Department of Transportation FHWA, 2014, pp. 26, 129
Intersection corner kerb radius	The radius of the kerb that joins the kerb of adjacent approaches to an intersection should be large enough to minimise the chance of lane encroachment due to overcorrection to avoid the kerb. However, the radius should not be so large as to make it difficult for pedestrians to cross safely.	U.S. Department of Transportation FHWA, 2014, pp. 27, 132
Intersection right-turn signalised control	Providing a protected right-turn phase at an intersection reduces the likelihood of a collision due to driver error misjudging an acceptable gap in oncoming traffic and interpreting vehicle speeds. Where a protected phase is not achievable, uniform signing advising drivers of the correct response to partial or no right-turn signals should be installed.	Austroads, 2004, p. 171 CAA, 2008, p. 24 European Commission, 2015, p. 104 U.S. Department of Transportation FHWA, 2014, pp. 28, 135
Intersection street name signs	Street name signs should be designed with a large enough font as to be easily readable and interpreted. In addition, retroreflective sheeting should be applied to enhance visibility.	Austroads, 2004, p. 181 CAA, 2008, p. 24 U.S. Department of Transportation FHWA, 2014, pp. 31, 152
Intersection angle	The preferred angle for intersections is right-angle. Decreasing the angle makes detection of and judgements about potential conflicting vehicles more difficult, as well as increasing the time it takes to manoeuvre through the intersection.	Austroads, 2004, p. 188 CAA, 2008, pp. 24, 27 European Commission, 2015, pp. 107, 110 U.S. Department of Transportation FHWA, 2014, pp. 33, 160
Intersection receiving lane width	Receiving lanes should be wide enough to allow for correct lane positioning upon completing a manoeuvre through an intersection. Narrower receiving lanes can result in greater encroachment in the opposing lane. However, the lane width should not be so wide as to make it difficult for pedestrians to cross safely.	Austroads, 2004, p. 191 CAA, 2008, p. 27
Intersection channelisation	Raised channelisation with sloping kerbs is recommended over pavement markings alone to increase detection of downstream geometric features (such as pavement width transitions and turning lanes).	Austroads, 2004, p. 193 U.S. Department of Transportation FHWA, 2014, pp. 34, 170
Intersection features to prevent wrong right-turn lane use	As well as channelisation, additional features can be installed to prevent the wrong lane use after a right-turn at a complex intersection. These features include lane use control signs, arrow markers, pavement markings, and delineation of median noises. Signs can also be used to prevent the use of the wrong lane where a major road with a median intersects a minor road.	Austroads, 2004, pp. 195, 197 European Commission, 2015, pp. 105, 106 U.S. Department of Transportation FHWA, 2014, pp. 35, 173

Intersection lighting	Fixed lighting installations at intersections is especially important for more complex intersections, such as those where the potential for wrong-way movements is high, those where evening and night-time pedestrian volumes are high, and those where a path-following adjustment is required from the driver (for example, when changing lanes).	Austroads, 2004, p. 199 CAA, 2008, p. 26 European Commission, 2015, p. 106 U.S. Department of Transportation FHWA, 2014, pp. 37, 181
Roundabout intersections	Roundabout intersections can be a beneficial treatment over stop or signal intersections if properly designed to meet the needs of a particular location. They are low-speed intersections, and when crashes do occur, they are typically low angle (sideswipe) at reduced speeds.	CAA, 2008, p. 25 European Commission, 2015, p. 97 U.S. Department of Transportation FHWA, 2014, pp. 41, 197
Intersection left-turn channelisation design	Designing left-turn channelisation with a tighter turning radius helps moderate the speed of the turn while also providing improved line of sight to see oncoming traffic. An adjacent pedestrian refuge island can also be included to enhance safety.	Austroads, 2004, p. 159 U.S. Department of Transportation FHWA, 2014, pp. 45, 215
Intersection combined lane use / destination signs	At more complex intersections combining lane use and destination signs can make it easier for drivers to properly position themselves in advance of a downstream manoeuvre, reducing demands for divided attention.	U.S. Department of Transportation FHWA, 2014, pp. 46, 215
Replace crossroads with two staggered T intersections	A popular treatment of unsafe rural cross-roads is to convert them into two single T-junctions where the two T-junctions are a suitable distance apart so that there are no safety effects resulting from weaving of vehicles across a staggered intersection or associated unsafe manoeuvres. It is safer to have two T-junctions rather than one cross road except occurs when the volume on the side-road is reasonably high, compared with the main road and when the volume of side-road traffic crossing the main road is low. This is because most crashes saved would be ones involving cross traffic from the side road.	Turner and Roozenburg,(2006)
Reduced conflict right-turn intersections	Some new intersection designs attempt to accommodate right-turns in unique ways to help reduce or even eliminate unprotected right-turns at an intersection. These designs include the median U-turn intersection and the restricted crossing U-turn intersection.	U.S. Department of Transportation FHWA, 2014, pp. 48, 218

Pedestrian avoidance treatments

High visibility pedestrian crossings	Designing pedestrian crossings that can be more quickly identified from a distance helps drivers avoid collisions with	European Commission, 2015, p. 101

	pedestrians. Lighting can also be used to provide additional visibility.	U.S. Department of Transportation FHWA, 2014, pp. 47, 216
Highway acceleration / deceleration lane design	Long parallel highway entrance ramps (rather than tapered) provide additional time for merging drivers to find a gap in traffic, which can be a more challenging task for some older drivers due to a diminished gap judgement ability.	Austroads, 2004, p. 204 European Commission, 2015, p. 92 U.S. Department of Transportation FHWA, 2014, pp. 58, 243
Interchange restricted or prohibited movements	Signs alerting drivers to restricted or prohibited movements (such as 'wrong way') should be designed with larger fonts and retroreflective sheeting to provide increased sign visibility and legibility. Pavement marking should also be used to supplement signage.	Austroads, 2004, p. 209 U.S. Department of Transportation FHWA, 2014, pp. 60, 252
Additional wrong way driving countermeasures	In addition to signage, additional treatments to counter wrong way driving should be considered, especially when exit ramps intersect with surface streets. These treatments could include channelisation and increased lighting.	U.S. Department of Transportation FHWA, 2014, pp. 63, 257

Signage, delineation and pavement markings treatments

Mainly intersection related

Upstream traffic signs	Upstream traffic signs can help give drivers more time to plan and reduce speeds as necessary. This particularly helps older drivers, who may have slower reaction speeds.	Austroads, 2004, p. 177 European Commission, 2015, p. 109
Intersection street name signs	Street name signs should be designed with a large enough font as to be easily readable and interpreted. In addition, retroreflective sheeting should be applied to enhance visibility.	Austroads, 2004, p. 177 European Commission, 2015, p. 109
Intersection stop and give way signs and holding lines	Stop and give way signs should be of a suitable size and reflectivity to enable an approaching driver to detect the presence of an intersection (as well as any traffic control devices) easily and quickly. 'Stop ahead' signs should be used when the road layout creates additional visibility issues. Conspicuous holding lines on the pavement also help provide additional definition.	European Commission, 2015, p. 107
Intersection advanced warning signs	Where intersections have poor approach sight distances, the provision of advanced warning signs can help accommodate slower reaction times.	Austroads, 2004, p. 191 CAA, 2008, p. 27
Intersection lane assignment on approach	The use of overhead lane assignment signs on the approach to an intersection helps drivers quickly identify which lane they need to be in for their intended manoeuvre.	Austroads, 2004, p. 193 U.S. Department of Transportation FHWA, 2014, pp. 34, 170

	Uncertainty about the downstream geometry can lead to hesitancy and diminish the driver's attentional resources available to identify and respond to potential traffic conflicts.	

Mainly rural mid-block

Horizontal curve guidance	Pavement marking and delineation devices provide path guidance on horizontal curves, particularly under adverse visibility conditions. Pavement markings should be bright, wide, thick, and structured to help them stand out even when there is surface water on the road. Centre line raised markers can also help provide delineation between lanes.	Austroads, 2004, pp. 217, 220 European Commission, 2015, p. 96 U.S. Department of Transportation FHWA, 2014, pp. 68, 260
Wider lane and shoulder widths on horizontal curves	Providing wider lane and shoulder widths on horizontal curves can help drivers maintain lane-keeping and speed while handling the curve.	Austroads, 2004, p. 223
Vertical curve guidance	Vertical curves can introduce hazards such as blocked views and unexpected intersections. Signage can be used to provide drivers with warning of what to expect and give them time to react.	European Commission, 2015, p. 96 U.S. Department of Transportation FHWA, 2014, pp. 70, 272
Passing lanes	Passing lanes should be designed with minimum lengths and longer sight distances to accommodate age-related difficulties in judging gaps and delayed decision making and reaction times. Setting a maximum distance between passing lanes can also alleviate potential collisions caused by drivers attempting to pass slower drivers using the opposing lane.	Austroads, 2004, pp. 225, 227, 230 U.S. Department of Transportation FHWA, 2014, pp. 71, 277
Advanced warning signs	The use of advanced warning signs such as Variable Message Signs (VMS) can be used to provide drivers with critical safety information, such as when to reduce speed. Other types of advanced warning signs, such as active speed warning signs, can be used to enhance speed limit compliance.	European Commission, 2015, p. 107
Highly reflective pavement marking material	The use of highly reflective compounds in pavement marking material can help increase the retroreflectivity and visibility of the markings, particularly at night and in poor weather conditions.	U.S. Department of Transportation FHWA, 2014, pp. 75, 285
Curve warning pavement markings	On curves identified as a safety problem, pavement markings can be used as a supplement to signage to help increase awareness.	U.S. Department of Transportation FHWA, 2014, pp. 75, 285
Dropped lane markings	When a through lane becomes a mandatory turn lane or exit lane, a 'dotted' lane line can be used to visually separate it from the	U.S. Department of Transportation FHWA, 2014, pp. 73, 284

	continuing through lane. This can help when a driver has missed lane signage.	
Supplemental pavement markings for stop and give way signs	Including pavement markings in advance of a stop or give way intersection can be used to supplement roadside signage which may not always be detected.	European Commission, 2015, p. 96 U.S. Department of Transportation FHWA, 2014, pp. 47, 217
Interchange exit signs and markings	Interchange exit signs and markings should be designed with a large enough font as to be easily readable and interpreted. In addition, retroreflective sheeting should be applied to enhance visibility.	European Commission, 2015, p. 110 U.S. Department of Transportation FHWA, 2014, pp. 54, 224
Highway entrance traffic control devices	Easily visible signage should be installed at highway entrance and exit points to help prevent drivers from making wrong-way manoeuvres (often due to reductions in the ability to integrate information from multiple sources).	U.S. Department of Transportation FHWA, 2014, pp. 56, 235
Highway exit delineation	Delineation of a highway exit gore should include raised pavement markers and retroreflective post-mounted delineators to help drivers easily identify exits.	Austroads, 2004, p. 207 U.S. Department of Transportation FHWA, 2014, pp. 57, 238

Railway level crossing treatments

Passive traffic control devices at highway crossings	To support increased detection of a passive railway crossing, post-mounted delineators with retroreflective sheeting can be installed along a section of the road leading up to the railway track.	U.S. Department of Transportation FHWA, 2014, pp. 90, 332
Illumination of railway crossings	Providing illumination of railway crossings may be effective at reducing night-time collisions and other collisions where visibility is a factor.	U.S. Department of Transportation FHWA, 2014, pp. 91, 343

The road surface treatments

High friction surface treatments	High friction surface treatments can be used to maintain pavement friction on road segments where the need for a safer pavement is the greatest, for example, horizontal and vertical curves. These surfaces amplify the effect of braking and help drivers regain control.	U.S. Department of Transportation FHWA, 2014, pp. 76, 287

Road Lighting treatments

Better road lighting in urban and rural areas	Older drivers generally need higher levels of road lighting than younger drivers to offset reductions in visual capabilities. Better lighting helps with driving at night, but also in poor weather conditions.	Austroads, 2004, p. 199 European Commission, 2015, p. 106
Interchange lighting	Acceptable interchange lighting reduces the frequency of crashes, particularly during night-time. Artificial lighting raises the illumination of the road environment so that reading and tracking functions can occur more easily.	Austroads, 2004, p. 199 European Commission, 2015, p. 107 U.S. Department of Transportation FHWA, 2014, pp. 60, 248

Adaptive LED lighting	Adaptive Light Emitting Diode (LED) lighting can be tailored to the demographics of road users in a particular area and changed depending on the current conditions using computer control systems. While LED lighting emits a higher amount of blue light than standard High-Pressure Sodium (HPS) lighting, which can have safety and environmental consequences, the Spectral Power Distribution (SPD) of the LED lighting can be adjusted to bring it more in line with HPS lighting.	Frith, 2021 U.S. Department of Transportation FHWA, 2014, p. 10

Appendix B-TTM related treatments

Non-variable signage and advance warning

A. Flashing Yellow Arrow Panel: Consistent use of a flashing arrow panel	"At construction/maintenance work zones on high-speed roadways (where the posted speed limit is 45 mph or greater) and divided highways, the consistent use of a flashing arrow panel located at the taper for each lane closure is recommended"	U.S. Department of Transportation FHWA, 2014, pp. 79
B. Lane Closure Advance Signing	A supplemental (portable) changeable message sign (CMS) displaying the one-page (phase) message LEFT (RIGHT, CENTER) LANE CLOSED should be placed 0.5 to 1.0 mile upstream of the lane closure taper is recommended. OR Redundant static signs should be used, with a minimum letter height of 8 in and fluorescent orange retroreflective sheeting, where both the first upstream sign (e.g., W20-1) and the second sign (e.g., W20-5) encountered by the driver are equipped with flashing warning lights throughout the entire time period of the lane closure	U.S. Department of Transportation FHWA, 2014, pp. 79
Sign Sheeting	To increase the legibility distance of ground-mounted work-zone signs, the use of fluorescent orange is recommended over the use of beaded high-intensity orange sheeting.	U.S. Department of Transportation FHWA, 2014, pp. 80
Legibility Distance	A minimum specific ratio of 1 inch of letter height per 30 feet of legibility distance should be used.	U.S. Department of Transportation FHWA, 2014, pp. 80

Portable Variable Message Signs (VMS)

Number of Phases	The MUTCD requires that no more than two phases be used on a changeable message sign (CMS). If a message cannot be conveyed in two phases, multiple CMSs and/or a supplemental highway advisory radio message should be used; alternatively, the action statement only may be presented on a single page/phase.	U.S. Department of Transportation FHWA, 2014, pp. 81
Display Time	Each phase of a CMS message should be displayed for a minimum of 3 s.	U.S. Department of Transportation FHWA, 2014, pp. 81

Units of Information	C-1. It is recommended that no more than one unit of information be displayed on a single line on a CMS, and no more than three units should be displayed for any single phase. A unit of information is one or more words that answers a specific question (e.g., What happened Where? What is the effect on traffic? What should the driver do?). C-2. For CMS messages split into two phases, a total of no more than four unique units of information should be presented.	U.S. Department of Transportation FHWA, 2014, pp. 81
Sign Content	When a CMS is used to display a message in two phases, the problem and location statements should be displayed during phase 1 and the effect or action statement during phase 2, as illustrated in Figure 64. If legibility distance restrictions rule out a two-phase display, the use of abbreviations [as specified in the MUTCD (FHWA, 2007)] plus elimination of the problem statement is the recommended strategy to allow for the presentation of the entire message in one phase	U.S. Department of Transportation FHWA, 2014, pp. 81
Legibility	For superior legibility: E-1. Only single-stroke lettering should be used for displays of alphanumeric characters on portable CMSs with the conventional 5- x 7-pixel matrix; double-stroke lettering should be avoided. E-2 As new portable CMSs are procured by a highway agency, the performance specifications of such devices should include a minimum character width-to-height ratio of 0.7 (complete character) and a maximum stroke width-to-height ratio of 0.13.	U.S. Department of Transportation FHWA, 2014, pp. 82
Sign Height	Portable changeable message signs should be elevated to a height sufficient to be seen across multiple lanes of (same-direction) traffic by approaching passenger car drivers.	U.S. Department of Transportation FHWA, 2014, pp. 82

Channelisation (Path Guidance)

Device Dimensions	The following minimum dimensions or properties for channelizing devices used in highway work zones are recommended to accommodate the needs of aging drivers:	U.S. Department of Transportation FHWA, 2014 pp. 82

	A-1 Traffic cones—36 in high, with two bands of retroreflective material totalling at least 12 in wide for night-time operations. A-2 Tubular markers—42 in high, with a single band of retroreflective material at least 12 in wide for night-time operations. A-3 Vertical (striped) panels—12 in wide. A-4 Barricades—12-in x 36-in minimum dimension. A-5 Drums—18 in x 36 in, with high-brightness sheeting for the orange and white retroreflective stripes (as per MUTCD guidelines).	
Device Spacing	Channelizing devices through work zones (in non-crossover applications) should be spaced at no more than a distance in feet equal to the speed limit through the work zone in miles per hour (e.g., in 40-mph work zone, channelizing devices should be spaced no farther apart than 40 ft). Where engineering judgment indicates a special need for speed reduction where there is horizontal curvature or through the taper for a lane closure, spacing of channelizing devices at a distance in feet equal to no more than half of the speed limit in miles per hour is recommended (e.g., in a 40-mph zone, space the devices no farther apart than 20 ft).	U.S. Department of Transportation FHWA, 2014, pp. 83
Reflectors	The use of side reflectors with cube-corner lenses or reflectors (facing the driver) mounted on top of concrete safety-shaped barriers and related temporary channelizing barriers is recommended, spaced (in feet) at no more than the construction zone speed limit (in miles per hour) through a work zone.	U.S. Department of Transportation FHWA, 2014, pp. 83

Delineation of Crossovers/ Alternate Travel Paths

Positive Barriers	Use positive barriers in transition zones and positive separation (channelization) between opposing two-lane traffic throughout a crossover, for intermediate- and long-term-duration work zones, for all roadway classes except residential.	U.S. Department of Transportation FHWA, 2014, pp. 84
Device Spacing	A maximum spacing (in feet) of one-half the construction zone speed limit (in miles per hour) for channelizing devices (other than concrete barriers)	U.S. Department of Transportation FHWA, 2014, pp. 84

	is recommended in transition areas, and through the length of the crossover, and in the termination area downstream (where operations as existed prior to the crossover resume).	
Reflectors	Use side reflectors with cube-corner lenses spaced (in feet) at no more than the construction zone speed limit (in miles per hour) on concrete channelizing barriers in crossovers (or alternately, the use of retroreflective sheeting on plastic glare-control louvers [paddles] placed in crossovers).	U.S. Department of Transportation FHWA, 2014, pp. 84
Screens	It is recommended for construction/work zones on high-volume roadways that glare-control screens be mounted on top of temporary traffic barriers that separate two-way motor vehicle traffic, when used in transition and crossover areas, at a spacing of not more than 24 in.	U.S. Department of Transportation FHWA, 2014, pp. 84

Temporary Pavement Markings and signs

Raised Pavement Markers2014, pp. 86	Where temporary pavement markings shorter than the 10-ft standard length are implemented, it is recommended that a raised pavement marker be placed at the centre of the gap between successive markings.	U.S. Department of Transportation FHWA, 2014, pp. 85
Increased Letter Height for Temporary Work Zone Signs	It is recommended that some “action” words (e.g., RIGHT and CLOSED) on temporary work zone signs on portable sign stands have a minimum letter height of 8 inches.	U.S. Department of Transportation FHWA,

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