Central Laboratories Report 02-527450

Minimum Performance Requirements for Delineation

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Contents

EXECUTIVE SUMMARY

This report describes a project to determine the visual performance required of delineation, and road markings in particular. The project was undertaken by Opus Central Laboratories with funding from the New Zealand Land Transport Safety Authority (LTSA).

The project included a review of visibility models to assess their suitability as a tool for establishing the visual performance of delineation, followed by the development of a methodology by which visual performance levels, appropriate to the visual demand of the road, could be established using these visibility models.

Minimum performance levels were identified for delineation for eight broad categories set out in LTSA publication RTS 5 " Guidelines for Rural Roadmarking and Delineation"

In establishing these performance levels issues considered included: whether older drivers are being adequately catered for; whether current levels of delineation are sufficient for truck drivers; and whether the use of new high performance materials is warranted.

Current Levels of Delineation and Levels of Service

In New Zealand, as in most countries, a mixed system of delineation is used. This comprises pavement markings, raised pavement markers, edge marker posts, chevrons and other reflective sheeting, tactile markings and signs. These devices collectively provide long-range delineation needed for route guidance, and short-range delineation for vehicle placement in the lane. The level of service that is provided to drivers will be a function of the number of elements used, quality of those elements, the consistency of those elements, and the extent to which delineation is provided in varying lighting and weather conditions.

Current levels of service for delineation are provided in a methods based approach, which defines the device or devices to be used and a level of maintenance to be applied. This approach, while reasonable, is not linked in a transparent way to a sound theoretical basis of driver needs and how the benefits increase with incremental improvements.

Driver Needs

To assist with understanding the benefits of providing improved delineation, driver needs from delineation were examined. The further ahead that a driver can see, the easier the driving task becomes. At night and in poor visibility conditions, the amount and quality of information available to help make predictions about the road ahead is reduced and delineation has an important role in compensating for the reduced visibility of the informal delineation. Some devices such as edge marker posts give long range guidance of the route ahead. Others, such as markings give guidance on vehicle placement. There is general agreement in the literature that a three to ten second preview time allows for easy driving, and two seconds is a recommended minimum to assist the driver to maintain a safe lateral position on the road. Care is needed in using this 'Minimum" as much safe driving occurs on roads which have no markings. It should be

viewed as, if markings are provided then to be of use to the driving task the markings should be visible for at least 2 seconds ahead.

As a group younger drivers (15-25 years old) have the best vision. Compared to them, other groups show small but steadily reduced visual ability up to the age group centred around sixty years old. Thereafter there is a sharp decline of about 12% for the 70 year old group and a further marked decline of about 30 % for the 80 year old group.

Older drivers have special requirements for delineation. For a 70 year old to achieve the same level of 'comfort' while driving (measured as preview time ahead) they would need much brighter lane markings than, for example, a 25 year old.

Modelling Visibility

Calculating preview times from first principles requires knowledge of marking size and position and reflective properties, vehicle type and position, geometry of the road and features such as lane width, illumination whether by daylight, streetlight or vehicle, and drivers' visual capabilities. Computer models have been developed which encompass these features and can be used for calculating preview times. Their development is at a point where they are a useful tool, although they do not yet fully address the driver's visual performance. Examples of such models are CARVE, OCARD, TARVIP (all from USA) and VISIBILITY (from Denmark).

The Danish model VISIBILITY was selected as the model of choice for this project, because of its ready availability and also because of the large number of factors it is able to take into account.

New Zealand Vehicle Attributes

The measurements VISIBILITY uses for driver's eye height above the road, horizontal distance of the driver from the front of the vehicle, headlamp mounting height and distance between headlamps were checked against New Zealand vehicle measurements and found to be very similar.

Setting Performance Levels for Markings

With the ability to model visibility from the properties of the road markings it is now possible to design road markings to provide a specified level of visibility. Design objectives are required but have not yet been defined by roading and safety authorities. Some interim design objectives and parameters are proposed together with a methodology to demonstrate how visibility could be used to set roadmarking performance. The design objectives and parameters proposed include that roadmarkings provide all drivers less than 75 years of age with at least two seconds driving time of forward visibility, and that markings be designed for conditions prevailing in the first hour of winter darkness.

The methodology to set performance levels was two-stage process: first the VISIBILITY model was used to establish trends of how visibility altered with factors such as driver age, marking properties, road geometry, vehicle lighting, road surface type, twilight, and street lighting. Next, using the traffic volume intervals in RTS5 (Road and Traffic Guidelines), an analysis identified factors such as expected numbers of drivers in the busiest hour, the likelihood of older drivers (from license statistics), the proportion of driving time on dipped beam, and the number of oncoming cars at any one time. The graphs of how visibility alters with the factors outlined above were then referred to and recommended reflectivity levels for the traffic volumes were determined.

Using this methodology and associated design parameters, it was established that for unlit roads, non reflectorised lines are suitable up to 250 AADT; lines reflectorised to 70 $mCd.m^{-2}.Lux^{-1}$ are required for roads of 250-750 AADT and enhanced lines of 150 $mCd.m^{-2}.Lux^{-1}$ are needed for roads with more than 750 vehicles per day. The increased reflective properties are primarily to cater for the older drivers. These reflective values can be used in conjunction with the table in RTS5 which recommends delineation including markings for rural roads.

Materials to provide these levels of reflectivity are commonly available. Currently most markings in New Zealand are non-reflectorised. Normal reflectorised marking materials such as those listed in the notes to Transit NZ specification M/7 achieve about 180- 200 $mCd.m^{-2}.Lux^{-1}$ when new and 70 $mCd.m^{-2}.Lux^{-1}$ is the replacement condition when the line should still appear to be reasonable. While the 150 $mCd.m^{-2}.Lux^{-1}$ is attained by current new markings, their life above this level will be fairly short and higher performance materials should be considered. Many of these materials, such as large diameter bright glass beads in acrylic paint, are already used extensively in Australia.

Considering solely the visual properties of the markings, the study found that there was little difference in the needs of car drivers compared to truck drivers, but motorcyclists in the same circumstances experience a reduction of about 20% in visibility distance.

It is noted that RTS5 is anomalous in that it does not recognise that the driving task is of equal visual difficulty for roads of the same traffic volumes, and becomes more difficult as the road narrows. In contrast RTS5 provides for more devices on the widest roads. Amendments to RTS5 are proposed but it is noted that further research may be needed to resolve the effects of edgelines on narrow roads.

Conclusions

1. Visibility models are a useful tool to establish trends of how visibility of road markings change under different lighting conditions, road marking properties, driver characteristics, and vehicle types. They interpret visibility as "driving time ahead for which a marking is visible".

2. The literature recommends preview times of 3 to 10 seconds of driving ahead. Devices such as edge marker posts provide some of this distance visibility, while markings are important to assist the driver in correct placement of their vehicle on the road. The literature

recommends that markings provide drivers with a minimum of two seconds of preview time.

3. Using visibility models it is now possible to design markings to achieve a specific level of visibility. Design objectives and parameters need to be specified at present road and safety authorities do not have suitable design objectives.

4. Therefore, some provisional design objectives and parameters are proposed. These include that roadmarkings provide all drivers less than 75 years of age with at least two seconds driving time of forward visibility and that markings be designed for conditions prevailing in the first hour of winter darkness.

5. Using these objectives and parameters for unlit roads non reflectorised lines are suitable up to 250 AADT; lines reflectorised to 70 $mCd.m^{-2}.Lux^{-1}$ are required for roads of 250-750 AADT and enhanced lines of 150 $mCd.m^{-2}.Lux^{-1}$ are needed for roads with more than 750 vehicles per day. These reflective values can be used in conjunction with the table in RTS5 which recommends delineation for rural roads.

6. RTS5 is anomalous in that it does not recognise that the driving task is at equal visual difficulty for roads of the same traffic volumes, and becomes more difficult as the road narrows. It is recommended that RTS 5 be amended but it is noted that further research may be needed to resolve the effects of edgelines on narrow roads.

1 Introduction

This report describes a project that was undertaken by Opus Central Laboratories with funding from the New Zealand Land Transport Safety Authority. The objective of this project was to determine the visual performance required of delineation, and road markings in particular. The project first established a suitable methodology based around visibility models, and then applied this methodology to identify the required performance of delineation on a typical hierarchy of New Zealand roads.

When considering performance levels for delineation, it is useful to first establish what the current practice is for delineation in New Zealand. That is, what types of delineation do we have, how do they work, and how are they selected for different roads? Once this background has been established, it is then necessary to look at why minimum performance requirements for delineation should be developed. Among the main issues to be addressed here are: whether older drivers are being adequately catered for; whether current levels of delineation are sufficient for truck drivers; and whether the use of new high performance materials is warranted. When setting a performance level for delineation, all of the factors which affect its visual performance need to be considered. These include driver attributes (vision, reaction times), lighting conditions (vehicle light type, oncoming vehicles), delineation size, placement, type and reflective properties, and background environment To achieve a balance between achieving a performance level that is safe and the cost of this safety, there is a need for a tool with which to explore how these factors interplay. Computerised visibility models, which have been recently developed, provide a means for doing this. Part of this project was a review of visibility models to assess their suitability as a tool for establishing the visual performance of delineation. This was followed by the development of a framework by which visual performance levels and level of service could be established.

Therefore, the following objectives for this project were identified:

1.1 Objectives

Identify a methodology centred around visibility models which can be used to set minimum performance levels appropriate to the visual demand of the road.

Identify minimum performance levels for delineation for eight broad categories for road delineation set out in in LTSA publication RTS 5 " Guidelines for Rural Roadmarking and Delineation"

2 Current Levels of Delineation and Levels of Service

2.1 Current Levels of Delineation

The main devices used for delineation are:

- Pavement markings (lane markings)
- Raised pavement markers
- Reflectorised raised pavement markers
- Audio tactile markings
- Edge marker posts

Publication RTS5, "Road and Traffic Guidelines" provides guidelines in New Zealand for rural roadmarkings and delineation. This guideline proposes no delineation for roads with traffic volumes less than 100 vehicles per day, and thereafter devices are added in a stepwise function as traffic volumes increase. Road width is also a factor. Centreline treatments are considered only when the road is wide enough. Devices are typically introduced initially for isolated use, then for continuous use as traffic volumes increase. Table 2.1.1 below shows the use for sealed roads.

Table 2.1.1: Delineation for Sealed Roads

AADT	Narrow Roads < 5.5 metres			Medium Roads 5.5 – 5.9 metres			Medium Roads 6.0 – 6.5metres			Wide Roads > 6.6 metres			Reflectivity of Marking (mCd. $m^{-2}.Lux^{-1}$)
	Nil	Isolated	Full	Nil	Isolated	Full	Nil	Isolated	Full	Nil	Isolated	Full	
< 100	✔			✔			✔			✔			N/A
100-249		EMP			EMP Centre			EMP Centre			EMP Centre		Non-reflectorised
250-499 Note 1		EMP			EMP	Centre		EMP	Centre		EMP Edge	Centre	
500-749 Note 1			EMP			Centre EMP		RRPM	Centre EMP		Edge RRPM	Centre EMP	70
750-999 Note 1			EMP			Centre EMP		RRPM	Centre EMP		RRPM	Centre EMP Edge	
1000-1499 Note 1			EMP			EMP Centre			EMP Centre Edge RRPM			Centre EMP Edge RRPM	150
>1500 Notes 1 & 2			EMP			Centre EMP			Centre EMP Edge RRPM			Centre EMP Edge RRPM	

Notes:

1. intersection markings not shown
2. new state highway spacing for EMP

AADT = Average Annual Daily Traffic
EMP = Edge Marker Posts
RRPM = Raised Reflective Pavement Markers
Centre = Centreline (dashed)
Edge = Edgeline

Table 2.1.2: Delineation for Unsealed Roads

AADT	All road widths
<100	Nil
100-499	EMP at isolated locations
500+	EMP continuous

Notes:

EMP = Edge Marker Posts

These devices have different functions. Rather than providing an increasingly brighter view of the road, they illuminate different parts of the visual field, both central and peripheral, and near distance and long distance.

Edge marker posts provide long-range delineation of the general route. They are effective in daytime and night time, and are especially effective in wet conditions at night time. Their position on the edge of the road, to the left of the vehicle, means they retain much of their visibility even with oncoming traffic. They also assist the medium range function on bends.

Centreline pavement markings (and white RRPMs) partition the wider roads. They provide short to medium range delineation, and are effective in daytime and night time. However their visibility is poor when there is oncoming traffic and often very poor in wet conditions.

Edgeline pavement markings provide short to medium range delineation and define the edge of the lane. They are effective in daytime and night time, and are much more visible than centrelines with oncoming traffic at night. However, as with centrelines their visibility is often poor in wet weather. Both types of marking however perform much better in the wet on chipseal surfaces than on smooth surfaces such as asphaltic concrete.

Reflectorised raised pavement markers provide both a long-range delineation of the route and particularly assist with short-range positioning by helping define the centre in oncoming traffic. Because they are reflective, as a visual device they are effective only at night and are especially useful in the wet. However depending on their spacing they can provide a tactile effect during both night and daytime driving.

2.2 Current Levels of Service

The level of service that is provided to drivers will be a function of the number of elements used, quality of those elements, the consistency of those elements, and the extent to which delineation is provided in varying lighting and weather conditions. That is, how much of the visual field is delineated, how bright, and for how much of the total driving time.

At present, level of service is specified through a range of documents:

- Number and type of elements is defined in RTS5 and MOTSAM, as shown in tables above.
- Consistency is implied by a specified frequency of maintenance and by a permitted failure rate, for example 90% of edge marker posts must be intact and they must be maintained every three days (or 7 or 18 days). These requirements are not in MOTSAM or RTS5 but are instead in the contract documents of the roading authority (e.g. SOMAC) or specifications such as the Transit New Zealand "C" Series Specifications.
- Functionality in most weather and lighting conditions, e.g. wet night time, is achieved in part by the choice of devices used. At present there are no requirements in New Zealand for performance other than in dry conditions.
- Quality, that is a combination of brightness and durability, is defined only by implication. For example, materials must be of an approved type and meet material

specifications. There is not always a direct connection between type approval and actual on-road performance. Approved materials are usually listed in notes to Transit New Zealand specifications.

All of the delineation has the function of defining the route ahead. However the different elements used have different characteristics and so provide different parts of the service. Some, such as edge marker posts, provide long-range information of the general route ahead. Others such as centreline markings give the more precise short-range information needed to accurately position the vehicle on the road. There is overlap of the two systems in the medium range where they strengthen the effect of each other. The choice of multiple systems is partly for the different stimuli they provide but also a realistic response to limitations of a single element providing the full delineation in all conditions. The use is also a balance of cost effectiveness.

The systems of delineation as set out in RTS5 are therefore a logical response to both the degradation of visibility with increasing traffic and the need to more accurately position the vehicle. This method-based approach is reasonable as it establishes a consistent pattern in how New Zealand roads are delineated. Drivers are immediately signalled by the delineation as to the quality of the road they are entering and therefore rapidly adapt their expectations and behaviour.

This current methods-based approach defines the device or devices to be used and a level of maintenance to be applied. Quality or level of performance is often not addressed directly, but rather only by implication. This approach, while reasonable, is not linked in a transparent way to a sound theoretical basis of the service being provided and how this service increases with incremental improvements. Because the underlying philosophy is not readily apparent, improvements to the system are usually made on an ad-hoc basis.

2.3 Weaknesses of the Current Approach

In the current system there is poor connection with the benefits for driver behaviour. Safety is usually considered as the only benefit of delineation. Other benefits such as reduced vehicle operating costs, travel time savings and improved road user satisfaction are not usually considered.

A lack of understanding of the connection of the benefits of improved delineation with driver behaviour may lead to unexpected results from improvements. For example more or brighter markings should help drivers see the road better and safety should improve. However, often the safety improvement is small and sometimes negative. An analysis of preview times shows that the better markings give improved preview times and consequently enable faster driving with the result that sometimes the original level of risk is maintained. Therefore safety may not improve.

Specifying intervention frequencies may encourage practices that actually result in less service to the driver. For example, if edge marker post maintenance is specified for every seven days, then the cost of this seven-day service may be traded off against less expensive posts which are more likely to break on impact. Drivers are therefore provided with an edge marker post system of which a significant proportion may be missing. In contrast, specifying a minimum acceptable level of defects encourages choice of higher performing posts and less frequent inspections, so that drivers are provided with a better, more consistent and more intact edge marker post system.

The next section looks at how drivers use delineation, with a focus on lane markings, to assist understanding of the performance requirements of delineation.

3 Review of Literature on Delineation and Driver Needs

3.1 How Drivers Use Delineation

One of the main functions of delineation is to guide the driver by marking the course of the road. Other functions include warning of hazards, and partitioning of traffic. Various forms and combinations of delineation can provide this information, such as edge marker posts that are used for long-range guidance, and lane markings that assist with short-range guidance. To understand how drivers use delineation for guidance requires an examination of what needs they have that can be aided by road markings. The following summary is based on a literature review by Rumar and Marsh (1998).

3.2 Driver Models

Various driver models classify driver needs in different ways. In Gibson and Crooks' (1938, in Rumar & Marsh, 1998) perception-based model, driver needs are defined in terms of "visual flow over the retina" (external stimuli in front of the vehicle that indicate the border of the road). Lane markings should support and enhance the visual flow over the retina, thereby facilitating perception of position, course, and speed along the road. In clear daylight conditions the flow over the retina is rich and so road markings are perceived peripherally and used unconsciously. In night driving, poor visibility conditions, and glare situations, the visibility of distant and peripheral stimuli used for orientation is reduced. At night road markings become more important and may be perceived in central vision and used consciously.

A different model proposed by Michon (1971, in Rumar & Marsh, 1998) and modified by Janssen (1979, in Rumar & Marsh, 1998) became the most commonly used driver model. It has three levels of driving tasks:

Table 3.2.1: Janssen's Task-Based Driver Model

Type Of Task	Action Required	Level Of Thought Required	Time Involved
Strategic	Planning	Conscious	Minutes
Tactical	Manoeuvring	May be conscious or unconscious	Seconds
Operational	Handling	Usually unconscious/ automatic	Milliseconds

With this model, the primary purpose of lane markings is to facilitate operational tasks. Lane markings may also influence tactical tasks, especially when the markings contain symbolic information such as 'no passing'. At night, drivers have to fixate more on lane markings, as driving tasks become less operational and more tactical.

Rumar (1986) developed another task-oriented driver model but with eight specified tasks. According to this model, when driving becomes more difficult (e.g. busy traffic) the driver's mental load increases. The main way drivers can reduce this mental load is by decreasing speed. The driving task most related to lane markings is maintaining track along the road, as lane markings help reduce the demand from this task.

A logical conclusion from Rumar's model is that lane markings allow drivers to travel faster than they would be able to if the markings weren't there. Consequently, accident reduction from improved delineation may be less than expected.

In their description of how drivers use delineation, Good and Baxter (1985, in Rumar & Marsh, 1998) distinguished between short-range delineation (used by drivers during reduced visibility conditions) and long-range delineation (used together with short-range guidance in good visibility conditions). Painted lines are considered good for short-range guidance, but poor for long-range guidance, while post-mounted delineators are good for long-range, but not for short-range.

3.3 Driver Requirements

The road itself is a priority source of information for drivers. Experiments have shown that as driving conditions deteriorated, drivers missed more and more information that was less important to the immediate task of vehicle navigation (such as warning signs, speed limit signs). However, the perception of the road was always maintained. This finding underlines the importance of road markings, as they enhance the information that drivers receive from the road.

Driver surveys have shown that drivers rate visual guidance as their main difficulty in night driving, reflecting the importance of the information conveyed by road markings in difficult driving situations. At night and in poor visibility conditions, the amount and quality of information available to help make predictions about the road ahead is reduced. Adequate lane markings should facilitate a driver's ability to make predictions about the road ahead, and provide feedback about the predictions made. The further ahead that lane marking assists a driver to see, the easier the driving task becomes. The importance of longer preview times is reinforced by the finding that the single-vehicle accident risk increases proportionately with the decrease of average geometric sight distance (Andersson & Nilsson, 1978, in Rumar & Marsh, 1998).

Rumar and Marsh recommend that drivers need a preview time of 5s for comfortable long-range visual guidance, so it is important that lane markings are visible from a long distance. There is general agreement in the literature that two seconds is an absolute minimum preview time. Two seconds preview time allows the driver to maintain a safe lateral position on the road, and is just adequate for a simple braking reaction. For curving roads, poor conditions, or allowing for the unexpected, 3s preview time is preferable (CIE 1992; Rumar & Marsh, 1998).

Liebowitz, Owens and Post (1982, in Rumar & Marsh, 1998) posited two main visual functions in driving: recognition and guidance. While the recognition function is impaired for all age groups when driving at night, the guidance function is less impaired in younger drivers than in older drivers. Therefore lane markings are particularly important for the visual guidance of older drivers driving at night time. Because the visual capabilities of drivers deteriorate progressively after about 40 years of age, especially at night, higher performing delineation is needed to provide the same perceived level of delineation as for the younger driver.

Delineation must also be able to be perceived in every lighting condition encountered. In daytime the sun angle and position is significant. At night time the lighting can be any combination of the factors including: the driver's own car headlights, street lighting, oncoming traffic, and distracting background lights. Rain and wet roads are acknowledged as a particular problem at night, but much more significant is the problem of glare from oncoming vehicles which, for older drivers, can mask out any delineation. Allowing for car headlights is not straightforward as the car lights could be any one of several headlamp types, which have differing distributions of illumination intensities.

4 Delineation For Older Drivers and Truck Drivers

The delineation needs of two special groups were considered: older drivers because their eyesight will have deteriorated, and truck drivers because they view the road from a different angle to car drivers.

4.1 Older Drivers

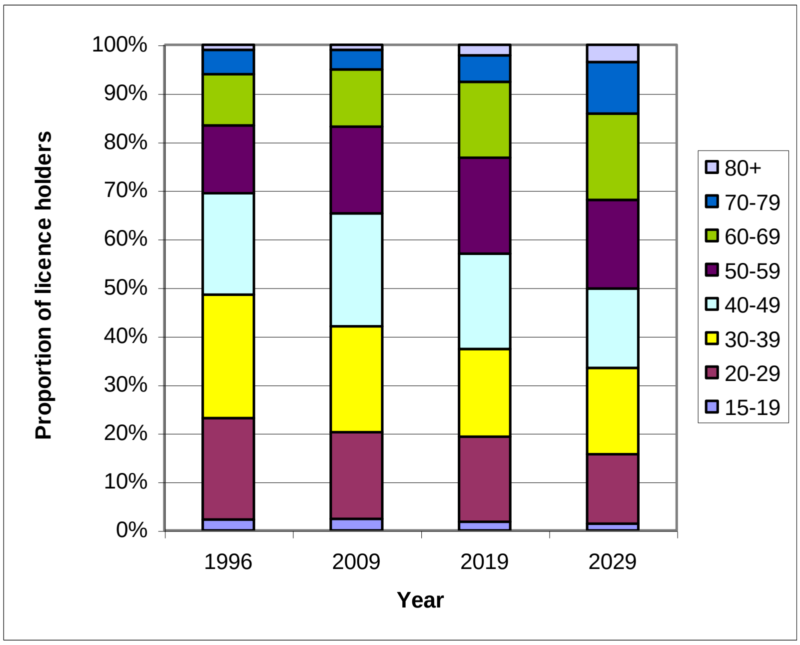
Whether current levels of delineation are adequate for older drivers (for the purposes of this report, those aged 60 and over) is an issue because often they cannot see as far as younger drivers, due to deteriorating vision. Although changes with age occur on an individual basis and may vary widely, it is inevitable that vision deteriorates with age. For example, by age 70, static visual acuity (that which is measured by licensing officers) is about 50% less effective. Dynamic visual acuity, or the ability to detect moving objects, also deteriorates. There are also changes in the ability to see in conditions of reduced light – for every 13 years of age over 20 years, the amount of light required to maintain the same visibility levels doubles. In relation to glare, a light source that causes a reduction of 20% in visual performance at age 25 causes a reduction of more than 70% at age 70. So, for example, for a 70 year old to achieve the same level of 'comfort' while driving (measured as preview time ahead) they would need much brighter lane markings than a 25 year old. As part of the objectives of the project we wanted to establish just how much brighter the markings would need to be to provide adequate delineation for older drivers.

To a large degree, older drivers appear to be aware of their limitations and will adjust their behaviour accordingly. Men and women aged over 70 drive less on highways and almost never on unfamiliar roads. It is believed that they do little long distance driving, avoid driving after dark, and become more dependent on others to drive them where they want to go. The LTSA's Travel Survey Report for 1997/1998 shows that the proportion of people making trips as the vehicle driver decreases from age 65 onwards, and that the proportion of trips made as passengers increases (LTSA 2000, Fig TR1, p. 44). One possible conclusion from this is that if delineation was improved by, for example, using brighter markings, older drivers would feel more comfortable driving further and more often, and so their mobility would be improved.

Another important reason why adequacy of current levels of delineation is an issue for older drivers is that New Zealand has a rapidly aging population. By 2031, one quarter of the population is expected to be aged 60 or older, which underlines further the importance of providing delineation that is adequate for older drivers.

The following figure shows predicted changes in proportions of New Zealand drivers. It shows that between 1996 and 2029, the proportion of drivers that are aged 60 or older will double.

Figure 4.1.1: Predicted Proportions of Licence Holders by Age, 2009-2029



4.2 Truck Drivers

A further part of this project was to test the perception that truck drivers see delineation differently because their higher seat position means they view the road from a different angle. The method used to test this perception was to model and compare preview times for car drivers and truck drivers in the same driving conditions, in order to establish whether it was necessary to include an additional factor for truck drivers in performance requirements for delineation. The findings are reported in the results in section 7 (see Figure 7.3.1).

5 Visibility Models

Visibility has been studied for many years. One of the major fundamental studies was undertaken by Blackwell (1946) who established the visibility of targets against a background of decreasing contrast under a range of illumination levels. These fundamental relationships established by Blackwell and others have been encompassed into mathematical models which have increasingly been combined into computer models that can be used to make predictions for "what if" situations posed. Research into driving and the role of delineation is ongoing and the models are evolving as more is understood about the driving process. Many of the assumptions and variables used in the models are derived from laboratory situations or on test sites, where the driving situation has been simulated to varying degrees. The models are then verified in the field.

5.1 Initial Development Of Visibility Models – As A Tool For Headlamp Evaluation

The models initially evolved as a tool in the development of headlamps, by which the performance of a number of different headlamps could be compared. One of the first of these was CHESS, which was developed by the Ford Motor Company. An associated seeing distance program, PC Detect, calculates the distance at which a given object (pedestrian or delineation) is just visible to the driver, given age/vision characteristics of the driver, car headlamp, geometrical factors, road speed characteristics, and effect of glare from oncoming traffic. The properties of illumination (street lighting, oncoming car headlamps) and retroreflectivity enable an object to be seen at night. However, they also act as a source of glare, which can discomfort or blind the driver. So visibility models such as PC Detect attempt to determine how to provide the maximum visibility to a driver with the minimum glare to other drivers. Glare can disrupt vision in three ways: it can reduce visibility (disabling glare), it can be a source of discomfort (discomfort glare) and can either act as a point source or be diffuse (veiling luminance).

Another model for evaluating headlamps is HEADS. HEADS is being developed by the NHTSA (National Highway Traffic Safety Administration) for use in determining acceptance criteria for new headlamps.

5.2 Delineation Models

5.2.1 OCARD Ohio (Dept of Transport) Computer Aided Road Delineation

OCARD determines the delineation requirements of chevrons and edge marker post spacing for specific topographical situations (e.g. curved sections. The developers are of the opinion that it is necessary to see four EMP devices ahead at all times when negotiating a bend, and OCARD determines the spacing requirements on this basis. The program also has the capacity to take crash data into account, and will decrease the spacing according to the crash statistics (Zwahlen & Schnell, 1995).

5.2.2 PC Detect

Although PC Detect was developed primarily for headlamp evaluation, it has also been used to determine minimum retroreflectivity requirements of road markings in a Canadian study (Barton, Sanderson, & Staplin, 1992). The program calculated that for a five second preview time with oncoming glare, the centreline needed to be increased to a level that is unattainable. However, the edgeline could provide sufficient visibility if it was 180 $mCd.m^{-2}.Lux^{-1}$or more (which can be attained).

PC Detect however has limitations; one being that it cannot take the effect of multiple types of delineation or multiple positions of one type of delineation into account. In the Canadian study cited above it could only take either the edge line or the centre-line into account but not both.

5.2.3 CARVE

CARVE is the most recent evolutionary development in modelling for delineation requirements. CARVE was developed at Ohio University by Helmut Zwahlen and Thomas Schnell of Iowa University, for the FHWA, with industry funding. The authors have assessed the merits of the existing models such as PC Detect and using current research (for example in-laboratory observations, simulations and field studies) revised some of the assumptions made in earlier programs to better simulate reality. For example the ability to detect contrast has been studied by a number of researchers in laboratory situations, and the data obtained is dependent on the approach used. The approach PC Detect used (CIE 1992) has been rejected by CARVE on the basis that it can only model the contrast detection of one object (one line). Schnell and Zwahlen argue that as multiple lines and delineators delineate a road, this situation is better modelled using data from another study (Blackwell, 1946), which gives in their view a more realistic (less conservative) output. Unfortunately CARVE was unavailable for use in the current project.

5.2.4 TarVip

Thomas Schnell of Ohio University is currently producing a new program called TarVip, which will be able to be used with OCARD. TarVip is intended to be similar to CARVE but with some improvements, such as the capacity to model for wet night visibility. This will be a useful addition because all the models discussed above assume clear night driving conditions due to the difficulty of modelling the effects of fog and rain.

5.2.5 VISIBILITY

VISIBILITY, a program that models for roadmarking lines, was developed as part of a collaborative European project (COST 'European Co-operation in the Field of Scientific and Technical Research') to establish the visual performance of roadmarkings. It also is limited to modelling one line at a time (i.e. a centreline or an edgeline but not both). VISIBILITY was selected as the model of choice for this project, because of its ready availability and also because of the large number of factors it is able to take into account. Some of these are vehicle type, diffuse lighting (from daylight or street lighting), driver age, vehicle speed, glare, headlight intensity, and vertical and horizontal curvature of the road.

For vehicle type, VISIBILITY has the option to select car, truck or motorcycle. For each vehicle type, VISIBILITY uses average distances for driver's eye height above the road, headlamp height above the road, distance between headlamps, and distance between headlamps and driver's eye height.

VISIBILITY allows driver's age to be input in 10-year increments, starting at 20 and going up to 80. Two internal factors vary according to the age that is input: the first relates to the reduction of the transmission of the eye with age, and the second relates to sensitivity to glare which increases with age due to the reduction of optical clarity of the eye.

Glare from oncoming vehicles is input into VISIBILITY as a value of veiling luminance from a table supplied, which gives values according to the number of oncoming cars (1-5) and the lateral separation to oncoming vehicles.

VISIBILITY is able to account for road geometry as it allows input for horizontal curvature to the left or right, and vertical curvature as the road climbs or drops away. The speed of the vehicle is input in kilometres per hour.

Headlamp illumination is accounted for by an option to have the headlamps off, on low beam, or high beam. For headlamps on, a value for headlamp intensity allows for variation between new, powerful headlamps and worn or dirty headlamps. Diffuse lighting conditions, from daylight or street lighting, are also able to be input into the VISIBILITY model.

Finally, properties of the roadmarking and the road surface are input. These include the retroreflected luminance of the roadmarking and the road surface, the position of the roadmarking line (left or right of vehicle), its type (continuous or broken), and the width of the lane and of the marking.

Once all the settings are chosen for these variables, VISIBILITY provides as output the preview time and the visibility distance ahead that the driver is able to see the roadmarking.

As VISIBILITY was developed in Denmark, it was necessary to examine how closely New Zealand vehicle attributes match the European measurements used in the VISIBILITY model. The next section addresses this.

6 New Zealand Vehicle Attributes

Relevant vehicle attributes relate to:

- headlamp beam distribution,
- geometry in terms of the position of the headlamps above the road, and
- the geometry between the driver and the headlamps

Three documents currently cover the requirements of vehicles registered for use in New Zealand:

- Traffic regulations 1976;
- Transport (Vehicle Standards) Regulations 1990 (VSR) (annotated to 12 November 1998), with gazettes being issued to update the regulations;
- LTSA Warrant of Fitness Inspection Guide (Dec 1997).

The LTSA is currently preparing a set of rules that will consolidate as one document and ultimately replace both the Traffic Regulations and VSR. The Warrant Inspection Guide is to remain as the LTSA's interpretation of the regulations and rules. The rules are intended to be performance-based.

6.1 Headlamp Distribution Requirements

The current headlamp specifications are already performance-based and will be carried over to the new rules system. All vehicle types (cars, buses, trucks, commercial vehicles) are required to comply with the same headlamp distribution requirements. These requirements include headlamp beam pattern, intensity and illumination distribution within the beam pattern.

The current regulations require the headlamps of all vehicles registered in New Zealand after 1961 to comply with either European, USA, Australian or Japanese standards. The Australian requirements (in the Australian Design Rule) are derived from the European ECE specifications. Japan produces for export car headlamps of type SAE-J for the US market, and ECE-JAS for the EEC and Australasian market. Japan has recently signed the 1958 Geneva Agreement with respect to motor vehicle compliance requirements. This means that Japan will now replace their specifications with those of ECE/EEC. The replacement process is anticipated to take place over the next 10 years.

Studies using PC Detect and photometric measurements (Sivak, Flannagan, & Miyokawa, 1998) have been used to compare the European and US (FMVSS) headlamp characteristics. These studies show the distribution differs slightly in that the ECE beam has a sharp cut-off to reduce glare on other vehicles, compared to the US beam.

Headlamp beam distributions for the Japanese ECE-J and the ECE types are thought to be very similar, if not the same (hence their amalgamation as one category in tables 2 and 3 below).

6.2 New Zealand Vehicle Statistics

The following data for 1996 was sourced from K. Chrun of the Transport Registry Centre, Palmerston North.

Table 6.2.1: Vehicle Fleet Composition By Vehicle Type

Vehicle type	Number	% Total
Bus	12,490	0.5
Car	2,106,343	80.5
Truck	85,768	3.0
Light commercial	333,382	13.0
Motorbike	78,345	3.0
Total	**2,616,328**	**100.0**

Table 6.2.2: Headlamp Compliance Of Cars

Compliance Standard	% New	% Used	% Total
ECE and ECE-JAS	39.7	35.2	74.9
FVMSS	0.2	0.4	0.6
Not known	24.2	0.1	24.3
Other	0.2	0.0	0.2
Total	**64.3**	**35.7**	**100.0**

Table 6.2.3: Headlamp Compliance Of Trucks

Compliance Standard	% New	% Used	% Total
ECE and ECE-JAS	37.3	22.9	60.2
FVMSS	1.5	0.6	2.1
Not known	37.3	0.2	37.5
Other	0.2	0.0	0.2
Total	**76.3**	**23.7**	**100.0**

6.3 Predicted Headlamp Compliance

Tables 6.2.2 and 6.2.3 show that compliance with ECE or ECE-JAS has been increasing in New Zealand, as the percentage of new vehicles complying with these standards is higher than that for used vehicles, for both cars and trucks. In the future the compliance with European requirements is predicted to continue increasing, and there is a possibility of a global standard with elements of both European and USA standards.

6.4 Headlamp Geometry

Trucks are required to comply with the same requirements as cars in terms of headlamp beam characteristics. However the mounting height of the headlamps and the eye height of the driver are higher for trucks. ECE require headlamps to be mounted at between 500mm and 1200mm above the road. Car headlamps are usually at the lower end of this and trucks at the higher end.

The measurements VISIBILITY uses for driver's eye height above the road, horizontal distance of the driver from the front of the vehicle, headlamp mounting height and distance between headlamps were checked against New Zealand vehicle measurements and found to be very similar.

Geometries for New Zealand vehicles are for similar or slightly improved lighting conditions.

7 Use of VISIBILITY Model to Determine Required Visibility Levels

7.1 Model Parameters

The model "VISIBILITY" was used to examine the effect of parameters relating to markings, driver's age and vehicle type on the visual performance of the delineation. As far as possible New Zealand-specific data was used, otherwise the default values of the model were accepted. VISIBILITY provides its output as distance from which the marking can be seen and, by using vehicle speed also calculates the preview time. The model was used to determine trends as various parameters were altered. These trends were mainly determined as preview time, though visibility distance has been used in some examples. Speed was set at 100km/h unless otherwise stated.

The New Zealand data on marking retroreflectivity was adjusted for use in the model. VISIBILITY assumes a 30 metre measuring geometry for measuring reflection properties, so the reflectivity value will translate to a higher value if measured by the 15 metre geometry units used in New Zealand (and Australia) at present. The table below shows reflective values as usually measured in New Zealand and Australia, and equivalent 30 metre geometry values, though it should be noted that these correlations would not be consistent in all circumstances. The text and figures of this paper are using the 30 metre geometry values. The visual performance of the marking is discussed in relation to a preview time of 2 seconds. This time is cited in the literature as being the absolute minimum needed. However, no minimum value has yet been identified for New Zealand.

Table 7.1.1: Typical Retroreflective Properties of Markings

Marking Example in Current New Zealand use	Qualitative Description	Retroreflective Value	
		15 Metre Geometry Mirolux 12	30 Metre Geometry MX 30
Worn non-reflectorised marking	Poor	70	50
New non-reflectorised marking	Fair	100	70
Worn reflectorised marking, replacement condition	fair	100	70
Worn reflectorised marking	Moderate – Good	150	100
New reflectorised marking	Very Good	200-250	150-200
Specialised products	excellent	250-700	250-700

Table 7.1.2: Dimension Used for Modelling

Road feature	Description	Dimensions used for modelling
Edgelines	Continuous	75 or 100mm wide
Centrelines	Continuous or dashed (3m with 7m space)	100mm wide
Carriageway	Single lane width	3.5m wide

7.2 Delineation Requirements for Older Drivers

Figure 7.2.1 shows the effect of driver's age on preview time at 100km/h for worn reflectorised and non-reflectorised edgelines, with headlights on low beam or high beam. There is a rapid drop-off in visibility of the marking for drivers aged 60 years or over. Figure 7.2.1 shows that for a minimum preview time of 2s, the non-reflectorised line is not bright enough for drivers 60 or older.

Figure 7.2.1: Preview Time v Age at 100km/hr

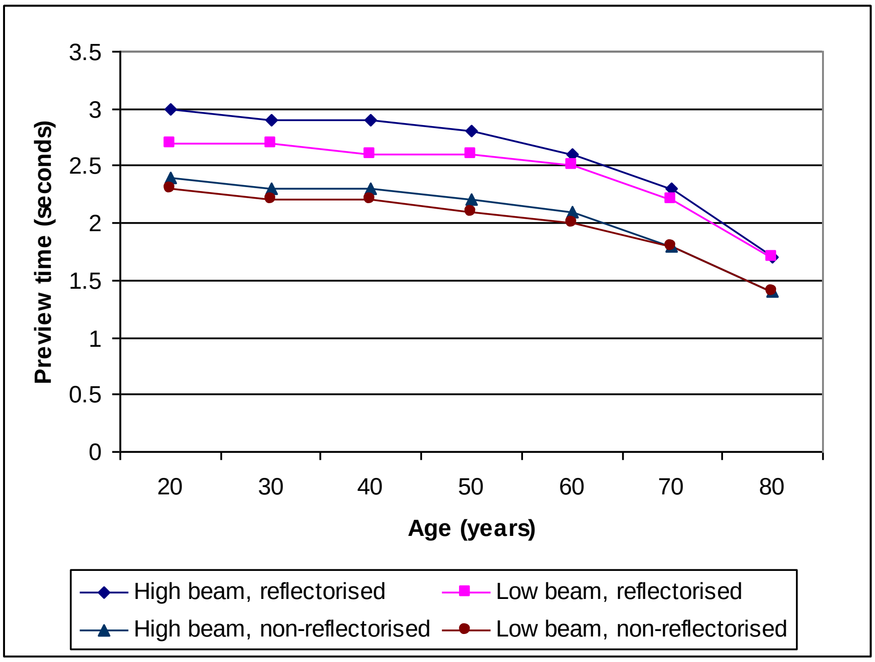


Figure 7.2.1 also shows that for drivers older than 75 years, even the reflectorised line is not adequate to provide 2s preview time. However the reflectorised line, which represents reflectorisation at the lower end of technology available, does give all drivers approximately 25% improvement in visibility over the non-reflectorised line.

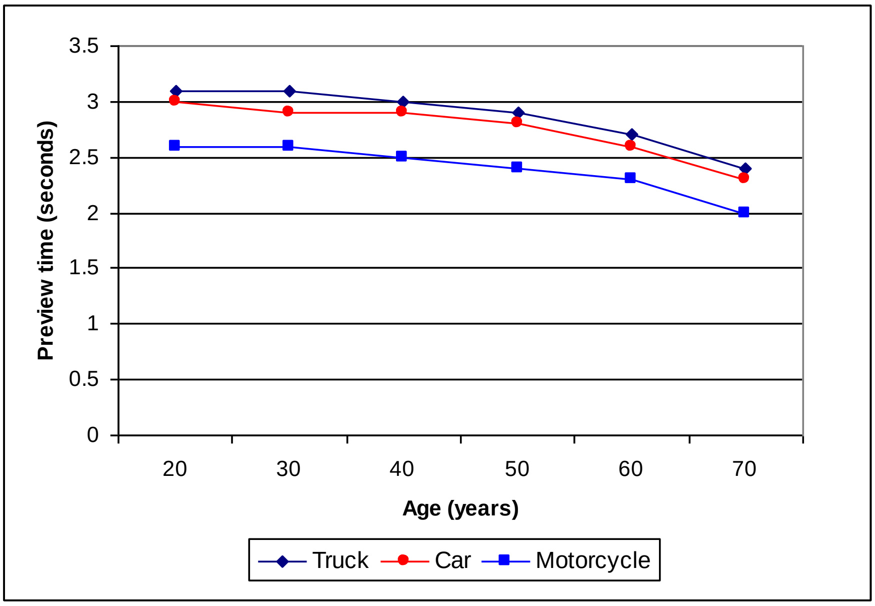
If we set the criterion for preview time at 3s, none of these worn lines are adequate, other than for the very youngest drivers.

Another way of looking at these results is to say that older drivers must drive much slower than 100km/h if they are to maintain a preview time of 2s.

7.3 Delineation Requirements for Different Vehicle Types

Figure 7.3.1 shows preview times for a car, a truck and a motorcycle across a range of ages. The line type used is a worn reflectorised edgeline and vehicle speed is 100km/hr. Figure 7.3.1 shows that cars and trucks have very similar preview times, with trucks only slightly better, and that motorcyclists have preview times about 20% less than the other vehicle types.

Figure 7.3.1: Preview Time v Age for Different Vehicle Types



7.4 Delineation Requirements with Glare from Oncoming Cars

Figure 7.4.1 shows preview times for a 20 year-old driver with 0-5 oncoming vehicles, and five different edgeline types. With 0 oncoming cars it is assumed that headlights are on full beam, but are dipped when other vehicles are present (i.e. 1 to 5 oncoming vehicles). It shows that adequate preview times are achievable with all the line types, although the best line (200 $mCd.m^{-2}.Lux^{-1}$) gives over one second (or 50%) more preview time than the poorest line (50 $mCd.m^{-2}.Lux^{-1}$) with five oncoming vehicles.

Figure 7.4.1: Preview Time with Different Lines and Numbers of Oncoming Vehicles (20 year-old)

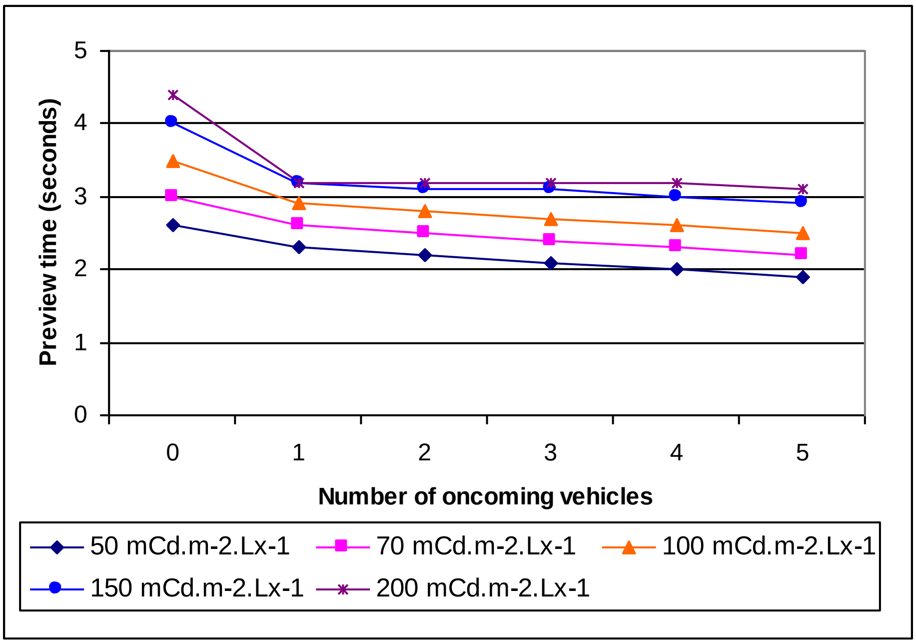
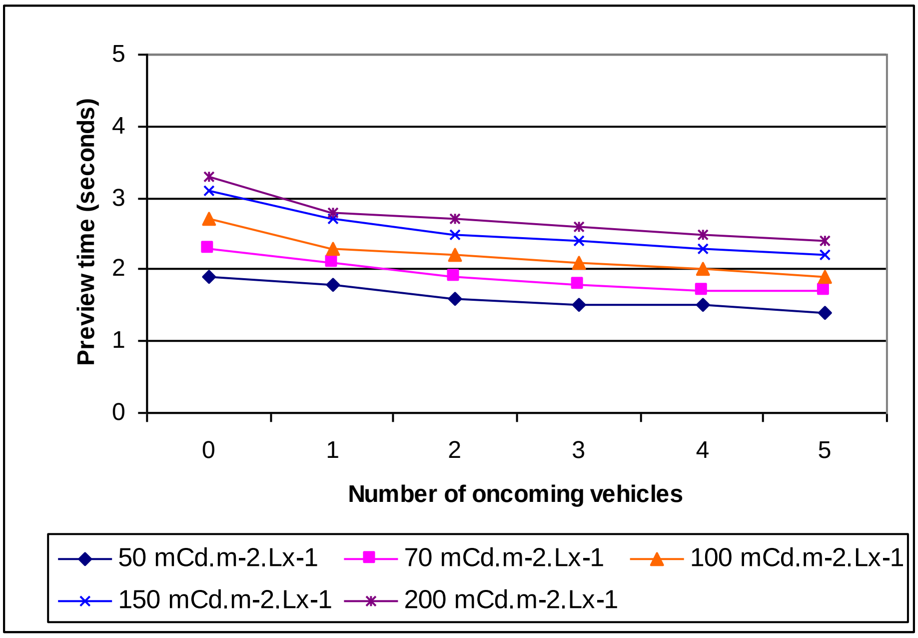


Figure 7.4.2 shows the same parameters as figure 7.4.1, but for a 70 year-old driver. In this case, only two line types (150 and 200 $mCd.m^{-2}.Lux^{-1}$) were bright enough to provide the 70 year-old with 2s preview time, with three or more oncoming vehicles. A comparison of figures 7.4.1 and 7.4.2 shows that choosing a line type (e.g. 200 $mCd.m^{-2}.Lux^{-1}$) that is bright enough to give at least 2s preview time for a 70 year-old would give younger drivers more comfortable preview times (more than 3s).

Figure 7.4.2: Preview Time with Different Lines and Numbers of Oncoming Vehicles (70 year-old)



Figures 7.4.1 and 7.4.2 show the effects of glare on preview time for edgelines of differing brightness. Figure 7.4.3 (modelled for an edgeline) and figure 7.4.4 (modelled for a centreline) enable comparison of the performance of edgelines and centrelines in glare conditions. Figures 7.4.3 and 7.4.4 show 20 and 70 year-old drivers on the same graph, and use reflectivity values typical of new reflectorised (180 $mCd.m^{-2}.Lux^{-1}$) and non-reflectorised (70 $mCd.m^{-2}.Lux^{-1}$) markings in New Zealand.

Figure 7.4.3: Edgeline Preview Times at 100km/hr

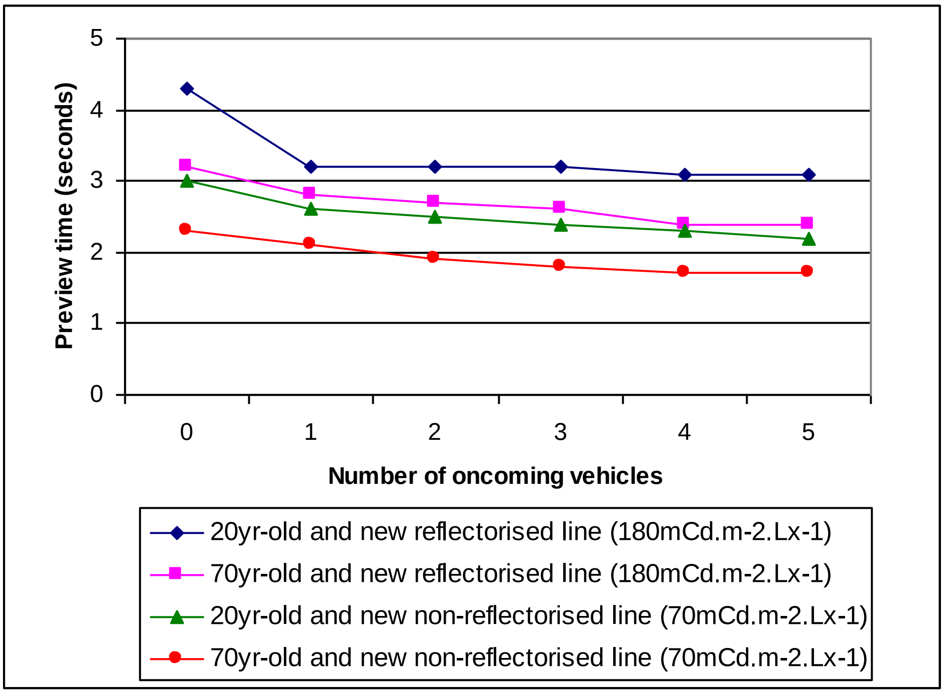


Figure 7.4.3 shows that a new non-reflectorised edgeline cannot provide 2s preview time for a 70 year-old when there is glare from two or more oncoming vehicles. A new non-reflectorised line is only just adequate for the 20 year-old when there are five or more oncoming vehicles, and it is important to remember that these reflectivity values are for new lines. Typical worn lines would have much lower reflectivity values (see Table 7.1.1). Figure 7.4.3 shows that a new reflectorised line can provide adequate preview times for both 20 and 70 year-olds.

Figure 7.4.4 shows the effect of glare on viewing the centreline, for 20 and 70 year-olds.

Figure 7.4.4: Centreline Preview Times at 100km/hr

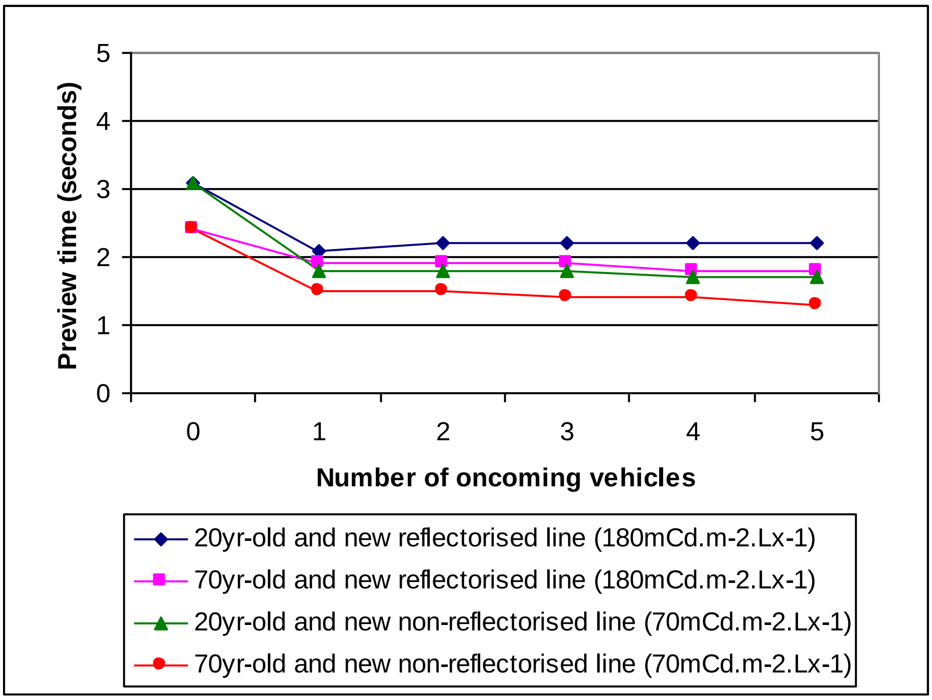


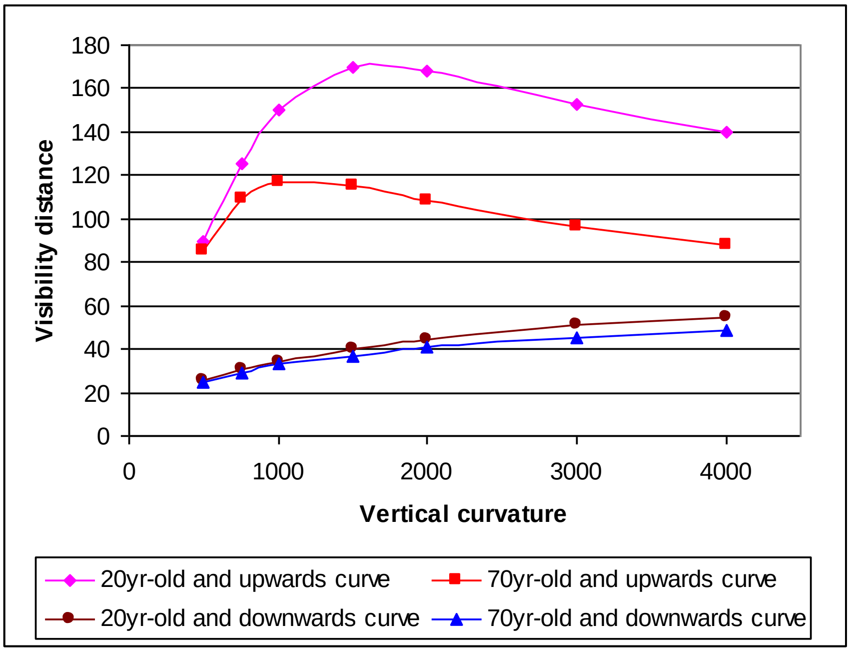
Figure 7.4.4 shows that compared with Figure 7.4.3, centrelines give much shorter preview times than edgelines, with oncoming vehicles. Here, only the 20 year-old viewing the new reflectorised line has adequate preview time. The new non-reflectorised line is inadequate even for 20 year-olds, and the new reflectorised line cannot provide adequate preview time for 70 year-olds.

7.5 Delineation Requirements for Roads with Vertical Curvature

Figure 7.5.1 shows the visibility distances of edgelines for vertical curvature, for both 20 and 70 year-olds. Sag (upwards) curves and convex (downwards) curves are modelled, and headlights were set to high beam in both cases. A reflectivity value for a worn reflectorised edgeline of 70 $mCd.m^{-2}.Lux^{-1}$ was used. Both age groups achieve very similar visibility distances with downward curves, but there is a large difference between visibility distances for 20 and 70 year-olds on upwards curves. Visibility distance is greatly reduced for 70 year-olds when travelling on upward curves of 1500m radii or greater, compared to 20 year-olds.

The good visibility on the upward curves arises from the tendency for the lights to "see across" the curve. The very short visibility distances on the downward curves should be treated with caution, as this may be in part due to the sharp cut off in illumination of the stylised headlights of the VISIBILITY model. Field observations however help confirm that visibility of a downward vertical curve is short.

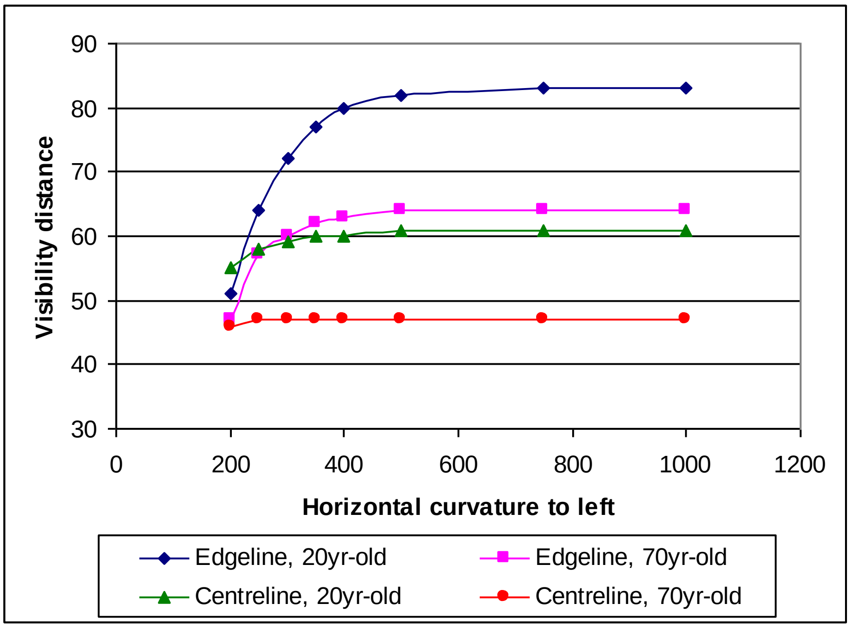
Figure 7.5.1: Visibility Distance v Vertical Curvature



7.6 Delineation Requirements for Roads with Horizontal Curvature

Figure 7.6.1 shows visibility distance under high beam for horizontal curvature to the left, modelled for 20 and 70 year-olds. Again a worn, reflectorised line with reflectivity of 70 $mCd.m^{-2}.Lux^{-1}$ was modelled. Figure 7.6.1 differs from figure 7.5.1 as it shows visibility distance for both edgelines and centrelines, while figure 7.5.1 is modelled for just an edgeline.

Figure 7.6.1: Visibility Distance for Horizontal Curves



As the curve tightens, the lines pass outside the span of the vehicle headlights and visibility distance decreases. The impact is greatest for the young drivers who normally can see a long way ahead so the curve taking the line out of their headlight span reduces their view on curves. At around 200 metres radius of curvature and less it is geometry rather than visual ability that dominates.

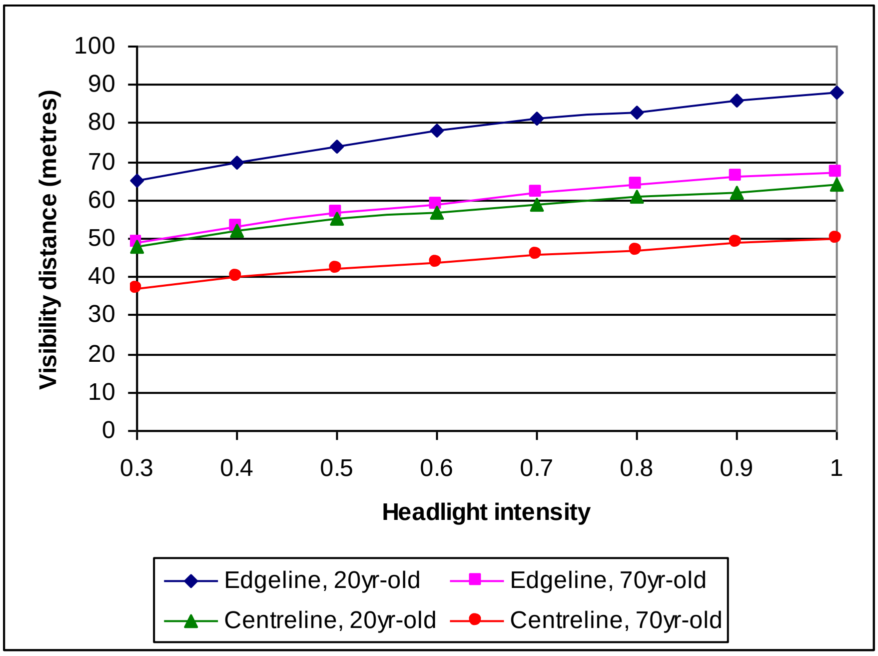
There appears to be little effect for the older drivers and centrelines. However the older driver can only see a short distance ahead with the centreline so here it is visibility rather than geometry which dominates.

Modelling for horizontal curvature to the right showed an equivalent effect, but there are some differences in the absolute visibility distance because of the different marking positions relative to the driver.

7.7 Delineation Requirements with Varying Headlight Intensity

Figure 7.7.1 shows visibility distance for edgelines and centrelines, for 20 and 70 year-old drivers travelling at 100km/h on a straight, flat road. A worn, reflectorised line of 70 $mCd.m^{-2}.Lux^{-1}$ was used. A headlight intensity of 1 represents new and powerful headlights, and values around 0.3 to 0.4 represent very old or dirty headlights. Figure 7.7.1 shows that visibility distance is greatly reduced to lower than recommended levels (60m visibility distance is approximately equal to 2s preview time, when travelling at 100km/h) when headlight intensity falls below about 0.7. Only the younger drivers viewing an edgeline are able to maintain an adequate visibility distance across headlight intensities.

Figure 7.7.1: Visibility Distance v Headlight Intensity



VISIBILITY is also able to model the visibility of markings under street lighting and daylight. This requires that two additional parameters are included in the modelling. These are Qd, the diffuse reflectivity of the marking and the road, and the diffuse illumination in Lux. The following table shows some approximate values for a range of different light levels.

Table 7.7.1: Approximate Illumination Values

Light Source	**Illumination (Lux)**
Very bright street lighting	30
Standard street lighting	10
Twilight	100
Cloudy day	1000
Bright, sunny day	10000

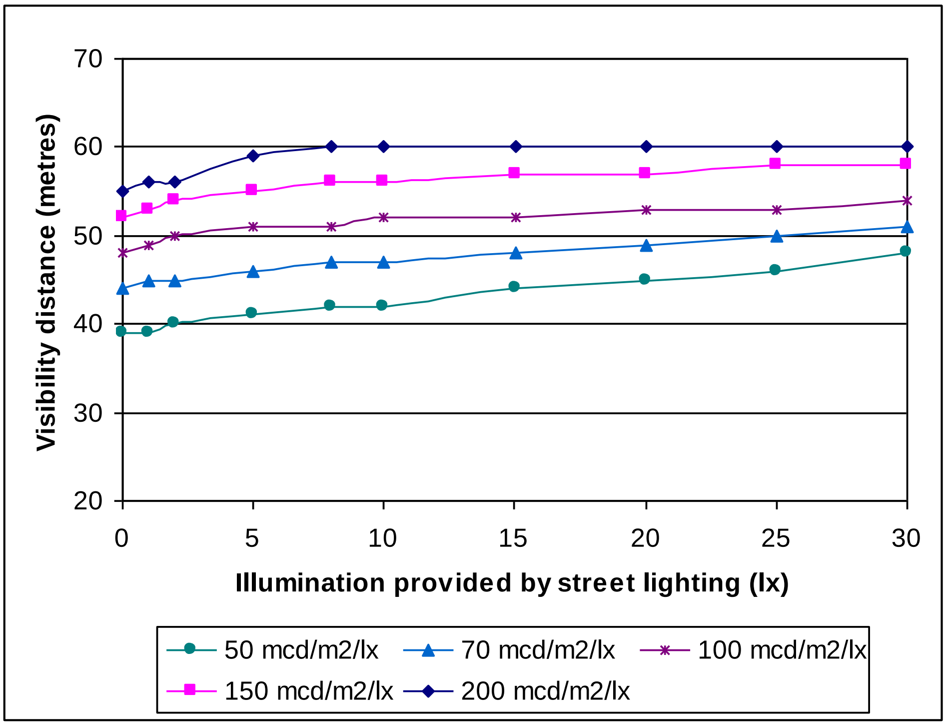
At this stage, Qd values for New Zealand road markings are not known, so they were estimated from the literature. These estimated values are shown in Table 7.7.2.

Table 7.7.2: Estimated Qd Values

Road Surface Type	**Approximate Qd**
Light seal/concrete	100
Chipseal	70
Asphalt	50
Marking type	**Approximate Qd**
New line	130
Typical line	95
Worn line	70

Figure 7.7.2, which is modelled for a centreline, shows that bright street lighting (30Lux) slightly improves visibility distance by around 5-6 metres when compared with very low light levels. At 50km/h, all the line types are able to provide adequate visibility distances. However, if travelling at 100km/h, only the two brightest lines (150 and 200 $mCd.m^{-2}.Lux^{-1}$) can provide adequate visibility for the 70 year-old driver. A centreline was modelled because the majority of locations that have street lighting are residential areas that may only have a centreline. Table 2.1.1 in section 2 shows that edgelines are only used continuously for wider roads that have a lot of traffic.

Figure 7.7.2: Visibility Distance v Street Lighting for a 70 year-old



7.8 Delineation Requirements in Twilight

Figure 7.8.1: Visibility Distance v twilight illumination

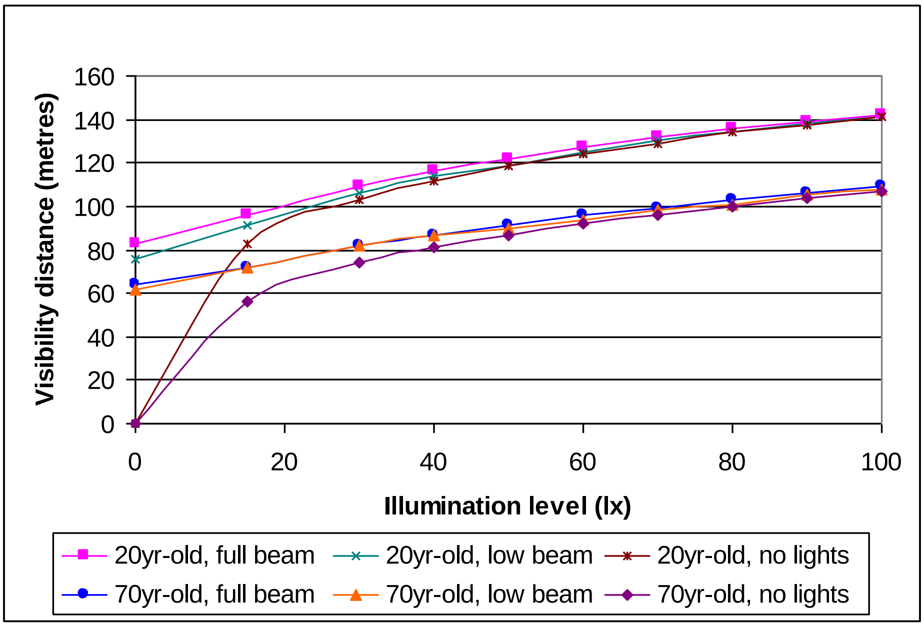


Figure 7.8.1 illustrates the different roles of retroreflectivity and reflectivity under street lighting or day light on marking visibility. The figure models a worn, reflectorised marking illuminated in two lighting conditions: headlights (dipped, full beam, and off) and

daylight. The figure shows three trends. When diffuse illumination is low i.e. near dark, the retroreflective properties of the marking dominate over diffuse retroreflectivity and give much better visibility of the marking with headlights on compared to headlights off.

Under bright street lights or mid-twilight the retroreflective properties play little part in conferring visibility of the marking. Diffuse reflectance of the diffuse lighting dominates and the marking is just as visible whether the vehicle headlights are on or off. 20 to 30 Lux marks the transition level. As usual the young driver has better visual ability under both lighting types than older drivers.

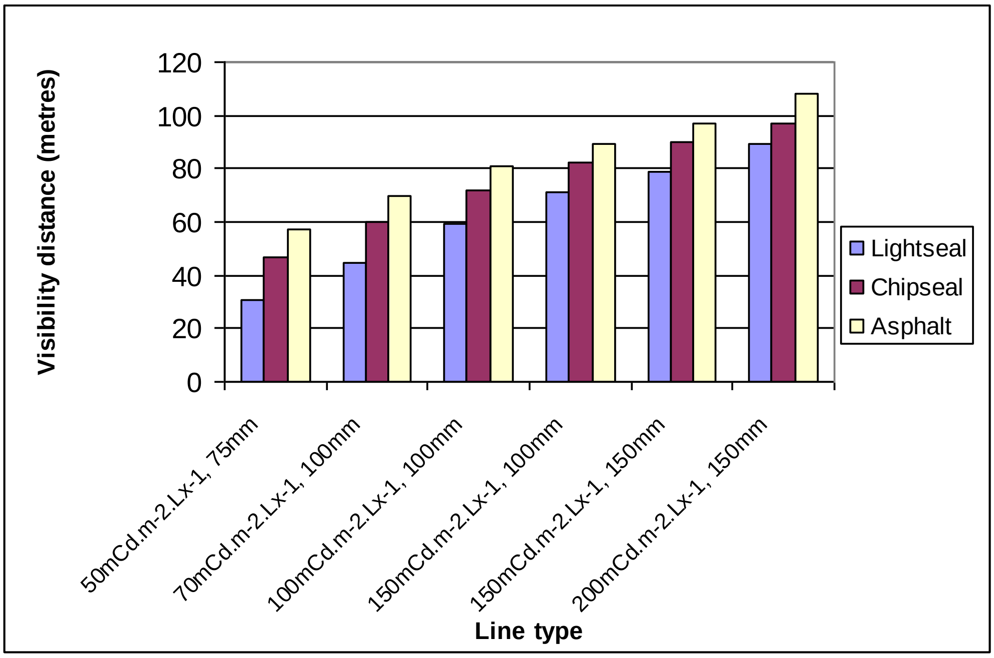
The third trend is for visibility distance to substantially improve under partial daylight conditions. Visibility distances under light twilight (100Lx) with or without headlights are about 80% greater for both old and young drivers than those of headlights only in dark night conditions.

7.9 Delineation Requirements for Different Road Surfaces

Figure 7.9.1 shows that the greatest visibility distance for each line type can be obtained on an asphalt surface, followed by chipseal, and with light seal providing the shortest visibility distances. This is due to the effect of contrast: because asphalt is the darkest surface, the lines show up best on this surface, and worst on light seal which is lighter in colour. Figure 7.9.1 also shows that the most reflective line, at 200 $mCd.m^{-2}.Lux^{-1}$, provides the longest visibility distances.

Modelled for 100km/h headlights on low.

Figure 7.9.1: Visibility Distance for Different Line Types on Three Road Surfaces, for a 70 Year-Old



8 Setting Performance Levels for Markings

The size, type and placement of markings are already well defined in the Manual of Traffic Signs and Markings. The performance of markings is not defined other than to identify which markings are and are not to be reflectorised

Until about 1996 the main way of ensuring marking performance was to maintain the marking at or above a certain level of intact paint. By inference, this marking would then be visible to drivers.

Since 1996 performance based specifications for markings have been developed. Performance is defined in terms of several key properties which can be measured on the road such as colour, day-time visibility, retroreflectivity and skid resistance. The key property for night-time visibility is retroreflectivity.

These performance-based specifications are now used on about 50% of the State Highway Network, and some Local Authority Networks. However, the performance levels stated are to some extent ad hoc, and have been arrived at by a combination of considering current New Zealand performance, international practice, cost and driver requirements. Without the knowledge of how these properties translate into visibility for the driver, the driver's requirements were not well defined.

With the ability to model visibility from the properties of the road markings it is now possible to design road markings to provide a specified level of visibility.

As with any design process, there needs to be a design objective . This could include:

- What level of visibility is to be provided;
- Will it be provided to all drivers, or just the majority i.e. the 85th percentile based on the number of licenses by age;
- Will the visibility level be provided in all conditions or only some, ie dry night-time, wet road at night, or in rain.

Design objectives have not yet been defined by roading and safety authorities. Some design objectives and parameters are proposed here together with a methodology to demonstrate how visibility could be used to set roadmarking performance.

8.1 Design Objectives

- Roadmarkings shall provide drivers (75 years of age or less) with at least 2 seconds of forward view (preview time)
- This objective shall apply to the road in a dry night-time condition. (This may subsequently be extended to wet night conditions.)

The literature shows that 2 seconds should be the absolute minimum preview time provided to drivers. The reflectivity value and marking size which provides this 2 seconds of preview time is dependent on the situation. For example, a poor 100 mm wide marking could provide this level of visibility for a young driver, driving on full beam on isolated roads. However, for an older driver driving towards heavy on-coming traffic on dipped beam, this same marking is likely to be barely visible. A visibility model can calculate the visibility distance for a driver of specific age in a specific situation only. Therefore, in designing the markings some design parameters need to also be proposed.

8.2 Design Parameters

- Roadmarkings shall be designed on the basis of traffic volumes in the first hour of darkness in winter This will vary across the country but 5:30-6:30 will be typical for mid April to mid August.
- In low traffic volumes it may not be practical to provide the recommended level of visibility at all times, such as when driving on dipped beam with oncoming traffic. This under-provision of visibility distance is therefore limited to occurring no more than 10% of the time. Drivers can adjust to this under-provision, for example by either short-term higher concentration, or by slowing down.
- Drivers approaching an oncoming vehicle would drive on dipped beam for about 30 seconds on average. As traffic volumes increase drivers will tend to remain on dipped beam even though there may be opportunities for them to go to full beam.
- In the absence of data, a 3:2 split in travel directions for the peak hour traffic volumes should be assumed.

The rationale for these objectives and parameters is that modelling in the previous section has shown that roadmarking visibility is dependent on:

- Lighting condition eg full beam or dipped beam, presence of oncoming traffic, presence of street lighting, amount of natural light (night-time or twilight);
- Driver age;
- Marking type, size, location, reflective properties;
- Vehicle type, headlight condition;
- Road geometry, eg straight, curved, flat or uphill;
- Vehicle speed; and
- Surface type.

For a given road, the marking and geometry are fixed and the main remaining variables are lighting condition and driver age. Traffic volume interacts with macroscale lighting conditions to form the micro scale lighting condition and can also be an indicator of the likelihood of older drivers being present. That is, time of year establishes whether it is likely to be daylight, dark or twilight; traffic volume then defines whether driving is likely to be on full beam or dipped beam and the likely amount of oncoming traffic. Because the demography of the licensed drivers is known, traffic volume will be an indicator of whether older drivers are likely to be present.

The time of day when a recommended visibility level needs to be achieved should be specified because traffic volumes and lighting levels vary according to time of day. A practical time appears to be the first hour of winter darkness (5:30 – 6:30pm in New Zealand), because for four months of the year (mid April to mid August) peak traffic volumes are travelling in the dark at this time. During this hour many drivers are travelling to or returning from work, or completing longer journeys started in more favourable lighting earlier in the day. With expected demographic changes these will include older drivers both as workforce participants, and as other travellers.

Profiles for traffic volumes show that for most road types the evening peak hour is 8-10% of the AADT traffic volume. The traffic profiles also show that about 25-30% of the driving is in darkness in winter. We can then derive a number of factors to assist in considering appropriate minimum visibility requirements for marking and delineation:

- The number of drivers in the busiest hour;
- The likelihood of older drivers (from license statistics);
- The proportion of driving time on dipped beam;
- The number of oncoming cars at any one time.

To assess the last two factors we considered that the flows are unlikely to be directionally even, so we have divided them in a 3:2 ratio. Those travelling in the minor direction will therefore face more opposing traffic. We have also assessed whether platoons of vehicles are likely given the hourly flow, as this will affect the number of oncoming vehicles and therefore visibility. The time that drivers will be on dipped headlights allowing for a 30 second approach time has also been calculated. From the proportion of time on dipped lights we set a limit (eg 10%) that we may under-design for.

This analysis enables the required modelling parameters of driver age, number of oncoming vehicles and full or dipped beam to be identified.

Table 8.2.1: Assessed Flows in Hours of Darkness and Time Driving on Low Beam

AADT	Total in Hours of Winter Darkness (30% AADT)	Total in First Hour of Darkness (8% AADT)	Opposing Flows (60:40)		Older Driver Likely	Platoons of Vehicles Likely	% of Time Per Hour on Low Beam
100	30	8	5	3	X	X	4%
250	75	20	12	8	X	X	10%
500	150	40	25	15	1 or 2 only	2 or 3 vehicles only	20%
750	225	60	36	24	√	√	30%
1,000	300	80	48	32	√	√	40%
1,500	500	120	72	48	√	√	60%

The table provides the basis for establishing the lighting condition and presence of older drivers and this can be used in conjunction with the modelling shown in Section 7 to identify the required reflectivity level.

Figure 7.6.1 shows that visibility distance is reduced by as much as 50% as horizontal curvature increases. For gentle curves the reduction occurs as the more distant marking is in the weaker light to the side of the main headlight beam. On sharp curves the marking is not lit by the beam. As the other graphs in section 7 are modelled for straight, flat roads, it is necessary to make an allowance for this decreased visibility. It is suggested that the performance of the lines should be interpreted as though 2.4 seconds (a margin of 20%) is the recommended preview time rather than 2.0 seconds.

Figure 7.3.1 shows that trucks have slightly better visibility than cars but motorcycles are about 20% worse. The markings are being designed for cars but it should be noted that veteran motorcyclists will be visually disadvantaged, but their proportion of the driving population is very small and the are unlikely to be driving at night.

From Table 3 it can be seen that for traffic volumes of 250 vehicles per day, older drivers at night are unlikely and most of the driving is on full beam.

Figures 7.2.1, 7.4.1 and 7.4.7 show that non-reflectorised lines are adequate for young and middle aged drivers in this situation.

Table 8.2.1 shows that for traffic volumes of 500 vehicles per day 20% of the peak hour driving will be on dipped beam and 1 or 2 older drivers are likely. In addition clusters of 2 to 3 oncoming vehicles will probably occur. Figures 7.4.1 and 7.4.2 show that lines of 70 $mCd.m^{-2}.Lux^{-1}$ are needed for younger drivers and lines of 100-150 $mCd.m^{-2}.Lux^{-1}$ for older drivers. Table 7.4.3 shows that the same reflectivity is needed for the centre-line. However as there are likely to be only a few older drivers, if cost was an issue then the $70mCd.m^{2}.Lux^{-1}$ lines could be used. These will under-provide for the older driver but will still be an improvement over existing non-reflectorised lines.

For traffic volumes 750 vpd and above Table 8.2.1 shows that older drivers will be frequently out at peak hour in winter and driving will be almost fully on dipped beam. Clusters of 5 or more oncoming vehicles will be frequent.

The figures referred to above show that with many older drivers present, lines need a retroreflectivity of 150 $mCd.m^{-2}.Lux^{-1}$. Figure 7.4.4 shows that this level is still inadequate for centre-lines. However, at these values, RRPM's are often used, and so the retroreflectivity of the centre-line is not an issue. Table 8.2.2 summarises these requirements.

Table 8.2.2: Recommended Line Types for Different Levels of AADT

AADT	Required Line Type
<250	Non-reflectorised lines
250 – 750	Standard Reflectorised Lines 70 $mCd.m^{-2}.Lux^{-1}$ (30 metre geometry)
>750	Enhanced Reflectorised Lines 150 $mCd.m^{-2}.Lux^{-1}$ (30 metre geometry)

Lines of 70 $mCd.m^{-2}.Lux^{-1}$ can be easily achieved by any of the standard reflectorised markings listed in the notes to the Transit New Zealand specification TNZ M/7. These same materials will have as new values of about 180 $mCd.m^{-2}.Lux^{-1}$ and could achieve the 150 $mCd.m^{-2}.Lux^{-1}$ needed for the older drivers but for a shorter period, or alternatively specialised markings could be used.

There is however a disjunction between the rationale of this report which is the basis for the recommended reflectivity values of table 8.2.2 and the rationale of the recommended delineation of RTS5 as shown in table 2.1.1.

This report identifies the role for markings is short range delineation of about two seconds' drive time ahead. The rationale is to provide this to all drivers. RTS5 however includes both short and long range delineation, and exhibits a form of rationing according to traffic volume and road width.

Table 8.2.1 showed that at up to 250 vehicles per day most driving occurs on full beam, and usually drivers are of an age where their eyesight will be reasonable. Full beam illuminated many features of the road side such as grass, shrubs, fences and poles, and these are sufficient for providing the short range delineation at these traffic volumes.

250-750 cars per day marks a transition where more driving is done on dipped beam, and some older drivers will be present. Not only will the visual task be more difficult for all drivers, but some have diminished visual abilities.

Above 750 vehicles per day the driving task is even more difficult. Driving is almost all on low beam, there will be glare from platoons of oncoming cars, and there will be a number of drivers with poor eyesight.

Table 2.1.1 is anomalous in that it does not recognise that the driving task will be even more difficult on the more narrow road for the same traffic volume. Instead in this table delineation features are removed as the road narrows. While this is logical for the centre line, and centre RRPMs, because there will be insufficient width, edge lines could still be provided, unless there were valid concerns that improved edge definition on narrow roads caused more head-on crashes. This may have to be resolved by further research.

The RTS5 table also has the concept of treated isolated sections as a way of ensuring that delineation is affordable. Without departing from this concept, the table below shows the suggested modification to the table, which recognises that the visual task is the same for equal traffic volumes and is more difficult for narrow road widths.

In this modification, centre lines and edge lines are used on the medium width roads to the same extent as wide roads. On narrow roads, centre lines are not used but edge lines are used, and their use is extended down to 100-250 vehicles per day. Additions to the table are shown in highlighted bold italics.

Table 8.2.3: Recommended Revisions to Delineation for Sealed Roads in RTS5

AADT	Narrow roads < 5.5 metres			Medium roads 5.5 – 5.9 metres			Medium roads 6.0 – 6.5metres			Wide roads > 6.6 metres			Reflectivity of marking (mCd. $m^{-2}.Lux^{-1}$)
	Nil	**Isolated**	**Full**	**Nil**	**Isolated**	**Full**	**Nil**	**Isolated**	**Full**	**Nil**	**Isolated**	**Full**	
< 100	✓			✓			✓			✓			N/A
100-249		EMP ***Edge***			EMP **Centre**			EMP **Centre**			**EMP** **Centre**		Non-reflectorised
250-499		EMP ***Edge***			EMP ***Edge***	**Centre**		EMP ***Edge***	**Centre**		**EMP** **Edge**	**Centre**	70
500-749			EMP ***Edge***		***RRPM*** ***edge***	Centre **EMP**		***RRPM*** ***edge***	Centre **EMP**		**Edge** **RRPM**	Centre **EMP**	
750-999			EMP ***Edge***		***RRPM***	Centre EMP ***Edge***		**RRPM**	Centre EMP ***Edge***		**RRPM**	Centre **EMP** **Edge**	150
1000-1499			EMP ***Edge***			EMP Centre *Edge* ***RRPM***			EMP Centre Edge **RRPM**			Centre **EMP** **Edge** **RRPM**	
>1500			EMP ***Edge***			Centre EMP *Edge* ***RRPM***			Centre EMP Edge **RRPM**			Centre **EMP** **Edge** **RRPM**	

9 Conclusions

1. Visibility models are a useful tool to establish trends of how visibility of road markings change under different lighting conditions, road marking properties, driver characteristics, and vehicle types. They interpret visibility as "driving time ahead for which a marking is visible".

2. The literature recommends preview times of 3 to 10 seconds of driving ahead. Devices such as edge marker posts provide some of this distance visibility, while markings are important to assist the driver in correct placement of their vehicle on the road. The literature recommends that markings provide drivers with a minimum of two seconds of preview time.

3. Using visibility models it is now possible to design markings to achieve a specific level of visibility. Design objectives and parameters need to be specified as at present road and safety authorities do not have suitable design objectives.

4. Therefore, some provisional design objectives and parameters are proposed. These include that roadmarkings provide all drivers less than 75 years of age with at least two seconds driving time of forward visibility and that markings be designed for conditions prevailing in the first hour of winter darkness.

5. Using these objectives and parameters for unlit roads non reflectorised lines are suitable up to 250 AADT; lines reflectorised to 70 $mCd.m^{-2}.Lux^{-1}$ are required for roads of 250-750 AADT and enhanced lines of 150 $mCd.m^{-2}.Lux^{-1}$ are needed for roads with more than 750 vehicles per day. These reflective values can be used in conjunction with the table in RTS5 which recommends delineation for rural roads.

6. RTS5 is anomalous in that it does not recognise that the driving task is at equal visual difficulty for roads of the same traffic volumes, and becomes more difficult as the road narrows. It is recommended that RTS 5 be amended but it is noted that further research may be needed to resolve the effects of edgelines on narrow roads.

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