ASSESSING PASSING OPPORTUNITIES

LITERATURE REVIEW

M J THRUSH
Works Consultancy Services Limited
Wellington, New Zealand

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PO Box 5084, Lambton Quay, Wellington, New Zealand
Telephone (04) 499-6600; Facsimile (04) 499-6666

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AN IMPORTANT NOTE FOR THE READER

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EXECUTIVE SUMMARY

This report describes a literature review undertaken in 1995 on the subject of Assessing Passing Opportunities. The objectives of the literature review were to develop a means for preliminary assessment of the need for enhanced passing opportunity, and to investigate the tools available to predict the effects of improved passing opportunity on a highway.

There is much research that indicates that frequent and effective passing opportunities are important for the operation of two-lane rural highways, particularly where two-way traffic flows exceed 500 vehicles per hour. There is evidence that safety can be improved by provision of passing lanes. One of the most important considerations in assessing passing opportunities is their effect on the level-of-service of the highway.

The literature showed that the important variables to consider in assessing passing opportunities are driver frustration, the percentage of the route length that has passing opportunity, traffic flows, length of passing lanes, gradient, and percentage of heavy vehicles. Warrants used in other countries to establish passing facilities were examined, but simply adopting one for use in New Zealand is unlikely to be the best option. Research is needed to develop a set of passing facility performance measures that are related to driver perceptions and take the variables listed above into account.

There are some general guidelines available that could be useful at the project feasibility stage. However, the complexity of the problem of assessing passing opportunities requires a tool specifically designed for this purpose. Of the tools available, a computer simulation model such as TRARR or TWOPAS seems most appropriate.

ABSTRACT

The Assessing Passing Opportunities Literature Review was undertaken in 1995 with two main objectives which were to develop a means of assessing the need for increased passing opportunity in the preliminary stages of a scheme evaluation and to evaluate the tools available to predict the effects of increased passing opportunities on highway operations. The report details the performance factors that should be considered in any assessment, summarises warrants used in other countries, and describes some tools used to evaluate passing facilities. The report concludes that there is a need to research some performance measures for New Zealand that are related to driver perception of the highway, and that a computer-based simulation model such as TRARR or TWOPAS would be most appropriate for determining the benefits of passing opportunities.

1 INTRODUCTION

1.1 Background

It is widely believed that the increasing numbers of slow vehicles on the rural two-lane highways of New Zealand has lead to an increase in the delays and frustrations experienced by drivers and that delays contribute to higher vehicle operating and travel time costs, and frustration where drivers take risks which can lead to accidents. The often anecdotal evidence is supported by Kaub (1990b) who found that delays of only 5% of total travel time were sufficient to cause erratic and unsafe passing manoeuvres in two-way flows as low as 500 vehicles per hour.

The provision of passing opportunities has been an issue for many years among those responsible for highway management and road users. Optimising passing facilities and predicting the effects of improved passing opportunities has become increasingly important as the resources available for major highway building programmes diminishes.

Determining the optimum location, length and spacing of improvements such as passing lanes and quantifying the resulting benefits, creates a complex set of problems.

It is possible to assess the benefits of increased passing opportunities in a variety of ways ranging from simple graphical relationships to full scale microscopic simulations. Many researchers have written on methods of evaluating passing lanes and many criteria for passing lanes have been proposed.

The broad aim of this literature review undertaken in 1995 was to identify which approaches were used overseas, with the intention of developing a method for use in New Zealand. The proposed approach was to select a model of passing behaviour and adapt it for use in New Zealand. This leads to the question of what is the level of complexity which will provide useful results for the New Zealand situation?

With this in mind, the literature review considered:

- The effect that availability of passing opportunities has on highway operations;
- The warrants for the identification of the need for improved passing opportunities and the means by which these may be provided;
- The tools available to evaluate the improvements; and
- The guidelines used to specify improvement strategies.

1.2 Literature Review

This literature review is the first part of a research project looking into the need, provision and benefits of passing opportunities on highways in New Zealand. The objectives of the study were to develop a means for preliminary assessment of the need or otherwise for additional passing opportunities on a vehicular traffic route and establish the tools for evaluating scheme appraisals for improving passing opportunities on vehicular traffic routes.

The project brief identified and emphasised literature from Australia, United Kingdom, and the USA, but database searches revealed only limited literature from the United Kingdom. However, a number of Canadian and South African references were also found which have been included in the review.

Section 2 of this report describes some of the effects that passing opportunity has on highway operations, including effects of delay, driver frustration and safety, as well as some methods for assessing the effectiveness of passing opportunities. This is followed by a section describing the warrants used outside New Zealand, including the means of identifying the need for passing opportunities. There is also a discussion on alternative passing opportunities that are used overseas. Section 4 describes various types of tools that may be used to evaluate passing facilities, including mathematical models and a selection of seven computer simulation models. The final section of the literature review discusses how the findings of various studies have been incorporated into guidelines for the design of passing opportunities.

The literature reviewed is listed in the References section at the end of the report. A review of the literature was undertaken, but many of the articles were concerned principally with sight distance requirements for safe passing and were beyond the scope of this project.

2 EFFECT OF PASSING OPPORTUNITIES ON HIGHWAY OPERATIONS

2.1 Delay and Frustration

Platooning behind slow vehicles is a major cause of delay and frustration on two-lane rural highways. The operational problems that are associated with two-lane highways are mainly concerned with such delays according to the Federal Highway Administration of the U.S. Department of Transportation (FHWA, 1987). Even if the delays are small, frequent speed changes and large amounts of time spent in platoons can give the driver the impression that the road provides a poor level of service. Hence the availability of passing opportunities will largely determine the level of service that a driver perceives on a highway.

For a vehicle to overtake another on a two lane road there must be a gap in the opposing traffic stream. Troutbeck (1981), cited in McLean (1987), considered the critical headways in opposing flow and the use of these by overtaking vehicles. Troutbeck showed that few drivers would attempt to overtake in a gap of less than 10 seconds, while most drivers would overtake in a gap of 30 seconds. This meant that the headway in the opposing flow would need to be of the order of 20 to 60 seconds to allow overtaking, assuming that both flows were travelling at the same speed. The typical critical headway was about 15 seconds, which translated to a 30 second headway in the opposing flow. However, the availability of a gap is only half the problem. A large headway is no use if the driver has insufficient sight distance to identify that the gap exists to pass safely.

Kaub (1990b) found that increased traffic volumes had a pronounced effect on the risk that drivers were prepared to accept in passing manoeuvres. This was the case even at relatively low flows. Kaub surveyed five sites where geometry restricted passing opportunities to 33 % of the road length. He made measurements of the time and distance between overtaking vehicles and opposing vehicles and the number of aborted passing attempts during weekends. He found that aborted passing manoeuvres were less than 1% of total passing manoeuvres with traffic flows of 200 to 250 vehicles per hour in the major direction, and 85 to 175 vehicles per hour in the minor direction. This increased to over 7% of all passes with traffic flows of 330 to 420 vehicles per hour in the major direction and 70 to 170 vehicles per hour in the minor direction. He concluded that passing opportunity at two-way flow levels of only 400-500 vehicles per hour appeared to be an integral part of the safe operation of two-lane rural highway.

2.2 Safety

The main concern with driver frustration is that it leads to drivers lowering their risk threshold and attempting passes in unsafe situations. This, coupled with the complexity of the passing manoeuvre, has lead many researchers to analyse accident records relating to the passing manoeuvre.

Kaub (1990b) provided useful indications on the effect that lack of passing opportunity had on a motorist's behaviour. The main conclusions were that the driver's decision threshold was negatively affected by the inability to pass and the effect increased significantly at two-way flows as low as 500 vehicles per hour. The number of aborted passing manoeuvres during heavy flows indicated that drivers could be overestimating their ability to pass safely.

Alexander and Pisano (1992) compared passing accidents on road sections marked with no-overtaking lines and road sections without no-overtaking lines. They concluded that lack of opportunities to pass on high volume two-lane highways appeared to lead motorists to attempt passing manoeuvres on road sections with no-overtaking lines marked, where sight distance was inadequate.

While increased risk taking is readily identifiable the identification of accident savings is less dramatic. Mohamedshah (1992) studied three unidentified states in the United States of America and showed that passing accidents were not a significant problem in the overall accident statistics for rural two-lane roads. While passing accidents were slightly more severe than non-passing accidents, head-on accidents were less frequent than other types, contrary to popular belief. This suggested that the potential for improving safety by changing markings in road sections where passing was permitted may be small. The conclusions of Mohamedshah are supported by Khasnabis (1986) who also found that passing related accidents were a small fraction of the total accident record.

Taylor and Jain (1991) calculated the mean accident rates with and without passing lanes for various sections. These sites were then divided into Annual Average Daily Traffic (AADT) ranges. They concluded that passing lanes were effective in reducing accidents on two-lane highways. The biggest benefits from fatal and serious injury savings came from mid-range AADT sites (AADT between 5 000 and 10 000 vehicles per day), with the greatest improvement in the overall accident rate occurring at sites with AADT greater than 10 000 vehicles per day. However this was mainly due to reduction in minor injury accidents.

Perhaps the most comprehensive study on accidents in passing lanes is that of Harwood and St. John (1985) referred to in Bester and Wolhunter (Undated). The conclusions of their safety study were that:

- Sites with passing lanes had 38% less accidents than those without;
- No significant difference was found in accident rate between the treated direction and the non-treated direction;
- Before-and-after studies strongly suggested that accident rates were reduced by provision of passing lanes. However, the short study period meant that differences were not statistically significant; and

- There was no indication of safety problems in the merge and diverge areas.

2.3 Measures of Effectiveness

One of the principal aims of passing studies is to predict where passing opportunities will be most effective. This requires not only accurate models to predict the effects of passing lanes, but also some way to quantify the effects. The evaluation measures must be applicable to a wide range of circumstances and be relevant to the driver's perception of the road.

A common measure within North American studies is the Percent Time Delayed. This represents the proportion of the journey spent travelling in platoons behind a slower vehicle and should represent the delay and frustration that results.

The percentage of time spent in platoons is noticeable to the driver. However the headway used to define a platooned vehicle must be carefully chosen since a small change in this parameter can result in a significant change in the Percent Time Delayed. This can even change the level of service that the road is defined to be providing, Khan et al. (1991) found that the percent of vehicles in platoons was a more sensitive measure of level of service than spot or average speed.

The definition of a platoon is important as bunching level measures are highly sensitive to the criterion used. Hoban (1984) listed some of the research done since the 1930s on defining free and following vehicles. Normann (1939) plotted the speed of vehicles and speed difference between vehicles against time-spacing between the vehicles and found some interaction between successive vehicles up to 9 seconds apart. The maximum interaction was at a headway of 1.5 seconds. Other researchers have used similar approaches. Underwood (1963) reported interaction at up to 6 seconds on two- and four-lane roads. Pahl et al. (1971) studied four-lane roads and found decreasing interaction over the range of 2.5 to 8.0 seconds. A study by Hoban (1984a) showed some vehicle interaction at up to 6 seconds.

Level of service criteria dominate the studies reviewed in this literature search, particularly those originating in North America where minimum level of service warrants provide the means for identification and justification of passing lanes.

Morrall et al. (Undated) used a platoon definition of 5 seconds in their planning and design of a system of passing lanes in Southern California. This selection is crucial given that the warrants for building the lanes were based largely on Percent Time Delayed.

Hoban (1984) cites the work of Boal (1974) and Branston (1976) who suggested two states of platooning existed, one where a vehicle was waiting to overtake and the second where the driver was content to follow. This being the case a measure such as the Percent Time Delayed will overestimate driver frustration. Unfortunately there is not sufficient information to assign headways to these states.

As well as establishing a need, measures of effectiveness should also be capable of identifying the results of an improvement. May (1991) studied five sections of passing lanes in California and showed that the number of passes per kilometre of passing lane was a good measure of effectiveness.

The five sites studied had different passing lane length, terrain type, traffic volume and traffic mix. Percent Time Delayed, percentage of vehicles travelling at headways of 2 seconds or less and percent of single vehicle platoons were also used as evaluation measures. The analysis found that lanes of 400 metres to 1200 metres were most effective, although different measures of effectiveness resulted in different rankings.

May also found that the number of passes was primarily affected by flow level while the Percent Time Delayed and Mean Journey Speed were affected by percent non-automobiles.

Staba et al. (1991) offered three ways of measuring the benefits of passing lanes:

- Percent traffic delayed;
- Platooning structure before and after the passing lane; and
- Number of passes made.

On the basis of field measurements, they selected the number of passes made as a measure of the effectiveness of passing lanes and while the number of passes made provided a means to compare the effectiveness of different passing lane configurations it did not readily identify the need for improved passing opportunities.

2.4 Summary

Frequent and effective passing opportunities are important issues for the operation of two lane rural roads where two way traffic flow exceeds 500 vehicles per hour, minimising both the time lost and the risks taken by frustrated drivers attempting to pass.

Overall the literature suggests that while the severity of passing accidents is higher than the average, passing accidents are a small proportion of the entire accident record. It appears provision of passing opportunity can significantly reduce the rate of passing accidents.

The ranking of projects is affected by the measure used and this highlights the need to link the measures of highway performance to their perception by the road users.

A number of measures have been used to consider the need for and effectiveness of passing opportunities but the Percent Time Delayed is one of the most popular because it is related to driver perceptions. Notable by its absence is the use of time lost as a measure of need. Two reasons are seen for this. Firstly, the measures discussed have been used for decades and were developed when the tools necessary to consider lost time were not readily available; and secondly, the actual lost time may be small and not in proportion to the frustration of drivers from being in a platoon.

The selection of a measure of effectiveness and the parameters that define it can have a major effect on the identification of the need for improved passing opportunities and the benefits that can be claimed for a project. Without such definitions level of service criteria cannot be compared. A link between driver perception and the available measures of effectiveness is required.

3 WARRANTS IDENTIFYING A NEED FOR PASSING IMPROVEMENTS

Passing lanes perform two important functions. These are to reduce delays at specific bottlenecks, such as steep grades, and to improve overall traffic flow on two-lane roads by breaking up platoons and reducing delays (Harwood et al. 1988).

Many researchers have tried to simplify the task of determining the need for passing lanes by producing graphical or mathematical relationships from large numbers of simulation runs or field measurements. In order to perform these simplifications it is necessary to establish criteria to measure the benefits that improvements bring. Hoban (1981) proposed that improvements may fall into three categories:

Standards	-	the speed and safety of individual vehicles.
Service	-	overtaking and bunching in traffic.
Capacity	-	maximum throughput, usually on a congested road.

How the effectiveness of a passing lane scheme was measured depended to a considerable extent on how these categories were weighted, and any model used to evaluate the options had to take all three categories into account. For instance, some analysis methods may focus on improvements to capacity and road geometry when these would be perfectly adequate if there was sufficient opportunity for passing to disperse bunches and reduce delays.

Hoban's criteria have been combined by many road controlling authorities to provide warrants or guidelines for passing improvements.

3.1 General Guidelines and Warrants

The highway authorities in the USA, South Africa and Canada determine the need for road improvements based on the provision of a minimum level of service. The criteria used to measure level of service are the percentage of vehicles in a platoon and the average speed. Each country adopts its own critical values.

The level of service method is criticised in Morrall et al. (Undated) for not recognising the advantages of passing lanes. The method was also deficient because it did not consider cost making it difficult to compare high and low cost options. Wolhunter and Polus (1988) described warrants as "surrogates for economic analysis" based on "fairly arbitrary but easily measured values".

3.1.1 United States of America

The 1985 Highway Capacity Manual (HCM) is used to evaluate roading projects on rural two- lane roads in the USA. It does this using level of service criteria. The criteria are based on Percent Time Delay which is defined as the percent of time that all vehicles are delayed while travelling in platoons due to the inability to pass. A relationship between the Percent Time Delayed and driver frustration appears to have existed but is not identified.

Separate criteria were used for the provision of climbing and passing lanes. The HCM stipulates climbing lanes should be provided when the requirements of two warrants, relating to speed and the level of service, are met. When the speeds of loaded vehicles fall to 25 kilometres per hour below the posted limit the speed reduction warrant is satisfied. The level of service warrant is satisfied when up-grade traffic exceeds 200 vehicles per hour and the up-grade truck volume exceeds 20 vehicles per hour. The warrant for climbing lanes takes the form of three charts. These are the grade, percentage trucks, and traffic volume in total vehicles per hour per lane. Lane configuration data, such as whether the roadway is divided, the lane widths and the lateral clearance, are also taken into consideration. In the specification for climbing lanes it is noted that the lanes begin well before speeds reduce to unacceptable levels and continue over the crest of a hill so that vehicles can regain speed before merging.

The chart-based procedure for determining need for passing lanes considers percentage trucks, road type, traffic volume in total vehicles per hour, terrain type and percentage of the route where passing is prohibited.

Passing lanes are provided where a sufficient number and length of roadway sections, with safe passing opportunities, cannot be obtained in the design of horizontal and vertical alignment and speed reduction warrant is not satisfied.

The level of service criteria in the USA is deficient in that it fails to take into account the effect of passing lanes on level of service.

To counter this problem Harwood and St John (1986) used the simulation model TWOPAS to develop an expression to predict the reduction in Percent Time Delayed based on the passing lane length, level of upstream delay and flow. While the expression was useful for the analysis of passing lanes it was not suitable for climbing lanes.

A further criticism of the level of service concept is that although it provides uniform criteria for assessing operating conditions, it does not allow for the cost of achieving a given level of service. The lack of any economic component also makes it difficult to compare low cost and high cost options.

3.1.2 Australia

The Australian guidelines published in "Rural Road Design" (AUSTROADS, 1989) discuss the role of demand and opportunity for overtaking and the justification for auxiliary lanes based on lane type, AADT, grade, approach speed and level of service. Overall the guidelines are very generalised.

More specific guidelines for the provision of overtaking lanes are based on tabulated ranges of traffic volume, percentage of slow vehicles and the availability of overtaking on adjoining road sections. The table has been prepared using TRARR (TRAffic on Rural Roads computer) simulation to produce benefits for benefit cost assessment. Given that somewhat dated standardised Australian costs have been used for the construction of unspecified lengths of passing lane, the application of these warrants to New Zealand must be questioned.

The provision of climbing lanes is based on the same criteria but the volume guidelines are reduced by 20% if truck speeds are reduced to 40 kilometres per hour. Where cost is prohibitive, slow vehicle bays can be used.

The Australian guidelines could be used in New Zealand for the initial identification of need but could not be used as a screening tool nor applied on a network-wide basis.

3.1.3 Canada (Alberta and Ontario)

In Canada, highways have historically been constructed as either two or four lanes. The only passing facilities provided on two-lane highways have been climbing lanes for slow vehicles. This has been due to the use of the HCM which does not allow for the effect of passing lanes on overtaking. Increasing driver frustration has lead to interest in providing passing lanes on some routes. It is in this context that Werner and Morrall (1984) sought to identify a measure that would represent driver frustration, identify the need for improvements and allow ranking of projects.

The relationship between the demand for and provision of passing opportunities is the key measure. It is understood that in excess of 10 000 drivers were surveyed as to their perception of the highway, but the results of the survey and in particular the relationship between the chosen measures and driver perceptions have not been located in the literature reviewed. The method does appear to be soundly based and has the potential to be used on a network-wide basis to identify and rank the need for improved passing opportunities.

3.2 Means of Identifying the Need for Improvement

Warrants for climbing lanes can be divided into five categories, Wolhunter et al. (1988):

- Truck speed reduction;
- Car/truck speed differential;
- Truck speed reduction in association with traffic volume;
- Car/truck speed differential in association with traffic volume; and
- Reduction in level of service.

These warrants are applicable to individual grades. The use of warrants based on truck speeds only are not favoured as they imply that car speeds are not affected by gradient. The use of a speed differential is therefore more desirable.

Wolhunter et al. (1988) proposed an alternative warrant based on a uniform total delay for all road sections. Adopting this approach resulted in more climbing lanes on higher volume roads and less climbing lanes on lower volume roads than current warrants permit. There is still research to be done in defining total delay and locating the "cut-off point" at which delay becomes meaningless as demand may exceed capacity on steeper routes.

Smith et al. (Unpublished), and Morrall et al. (1994) proposed different criteria for passing lanes. In order to undertake simulation studies of passing opportunities they suggested that the warrant for passing lanes be met by:

- 60 % time spent following; and
- Provision of assured passing opportunities at regular intervals based on AADT.

The warrants for passing lanes with this criteria would be subject to various physical restraints. In their trial of these criteria, the micro simulation model TRARR was used to obtain level of service data for future years. The figures for 1990 and 2010 were compared for each proposed lane and then lanes were ranked based on ease of construction and capital costs.

It would appear that while warrants, or guidelines, are proposed to identify the locations where improved passing opportunities may be required the recommendations are sensitive to the criteria used which must in turn be related to driver perception.

The South African study of Bester and Wolhunter(undated) concluded that warrants for climbing lanes should be based on economic evaluation taking into account cost of construction and maintenance, time savings, vehicle operating cost savings and accident savings.

The method used in New Zealand for deciding which road projects are to be funded is to rank them on the basis of their Benefit/Cost ratio (TNZ 1991). Unlike the level of service or warrants, which are based on the identification of need, the Benefit/Cost ratio determines whether the need is sufficient to justify the proposed solution.

An alternative used in the USA is the cost effectiveness ratio (FHWA 1987). Such ratios may be based on measures such as the percentage accident reduction or the reduction in Percent Time Delayed per ten thousand dollars expenditure. These ratios seek to account for the cost implications of a proposed project and rank options. Such measures have the advantage of screening out inferior solutions without excessive analysis.

3.3 Provision of Alternative Passing Facilities

The warrants and guidelines identified in 3.2 deal almost exclusively with passing and climbing lanes, but there are other methods of providing passing opportunities. Rather than place the responsibility for passing on the following vehicle, there is the potential for the slow vehicle to move out of the traffic stream and allow the following vehicles to pass.

3.3.1 Slow Vehicle Turnouts

Slow vehicle turnouts are not auxiliary lanes. They are areas on the side of the road where slow vehicles can pull over and allow other traffic to pass. It is a legal requirement in the USA for vehicles that are delaying five or more vehicles to turn off the roadway and allow the followers to pass wherever opportunity to do so safely exists. Turnouts are long enough to allow the slow vehicle to keep moving while it pulls over out of the traffic stream and rejoins it without having its own progress impeded. Turnouts are particularly useful in mountainous terrain and other areas where the cost of providing a full auxiliary passing lane is prohibitive. But turnouts can be safety hazards if traffic volumes are too high or the purpose of the turnout is unclear, or if the following motorist cannot see the end of the turnout. Heavy vehicles may be reluctant to use turnouts if they think they might have to stop and wait at the point of rejoining the traffic stream. To avoid this, a series of turnouts can be provided so that platoons of more than two vehicles are unlikely to form. The FHWA (1987) suggests that turnouts are most effective on lower volume highways where long platoons are rare. When used in series, a typical spacing is 2 to 5 kilometres.

The slow vehicle turnout is a longer version of the slow vehicle bay which is becoming more frequently used in New Zealand. While a slow vehicle turnout may cost more to construct, the likelihood that the slow vehicle will be forced to stop is greatly reduced. This makes a slow vehicle turnout a more attractive option than a slow vehicle bay for drivers of slower vehicles.

3.3.2 Wide Shoulders

Finland has 200 kilometres of motorway standard two-lane rural road. This road has motorway standard alignment and grade separated intersections. The shoulders are 2.5 metres wide and paved. A study of passing behaviour by Pursula and Siimes (1993) showed that the shoulders were used by 20%-40% of all overtaken cars and 40%-80% of all overtaken trucks to allow more room for overtaking. In addition, the shoulder was used by about 10%-30% of opposing traffic to give the overtaking vehicle more room. Finland had followed the lead of other countries by experimenting with three-lane roads, where two-lane segments alternate from side to side, creating passing lanes averaging in length from 1.0 to 1.7 kilometres. The initial results have been promising. Both field measurements and TRARR simulations showed a small increase in travel speeds and a substantial increase in the number of passes in comparison to the high class two-lane rural road.

Shoulder driving is common in many states of the USA, particularly Texas, where many two lane rural roads are 13.4 metres in total width (FHWA, 1987). Where a wide paved shoulder exists, it is regarded as a courtesy to pull onto it to allow another vehicle to pass. In effect the shoulder serves as a continuous slow vehicle turnout. This is actually illegal, but not enforced. The FHWA recommends shoulder widths of at least 2.4 metres and preferably 3.1 metres to be effective as passing aids. Furthermore the shoulders must be strong enough to withstand heavy vehicle traffic without excessive deterioration.

Fambro et al. (1981) found that the effectiveness of shoulder driving was dependent on traffic volume. Shoulder driving at flows over 200 vehicles per hour one-way had the effect of raising average speed by at least 10%. Some of the speed increase could be due to the presence of the wide shoulder. About 5% of traffic used the shoulder at any one location, but the percentage of vehicles in platoons was reduced to less than 20%. The study concluded that it be made legal, though not compulsory, to drive on the shoulders and that wide paved shoulders be provided on all roads with one way flows greater than 200 vehicles per hour.

There are problems with shoulder driving. Morrall (1984) cited in FHWA (1987) showed that at very high volumes of traffic drivers were reluctant to use shoulders as they could have difficulty re-entering the lane. This is a similar problem to that identified with the use of slow vehicle turnouts on more highly trafficked roads. Improper use of the shoulder by passing on the wrong side and driving three abreast has been observed. Uncertainty among some slower drivers about whether to use the shoulder and frustration caused when some do not pull into the shoulder indicates that, while they are an aid in dispersing platoons, wide shoulders cannot be a substitute for passing lanes.

4 TOOLS TO EVALUATE PASSING FACILITIES

4.1 Mathematical Models

4.1.1 Introduction

From the mid 1950s to the mid 1970s many researchers proposed mathematical formulae for modelling two-lane, two-way traffic flow (McLean 1987). Mathematical models make gross simplifications in assuming random flow and treating vehicles as points occupying no space. There are additions which can be made to formulae to provide more realistic spatial characteristics but the complexity of the model becomes too great. With the availability of computers, research efforts moved toward microscopic simulation. However McLean argues that mathematical models still have a place in interpreting the results of the more complex simulations.

4.1.2 Overtaking Opportunities

McLean (1987) proposed the use of a Poisson distribution to model headways in both traffic streams. The model provided a good approximation of overtaking opportunities when the distribution of overtaking opportunities was controlled mainly by the availability of gaps in the opposing flow. When the available sight distance dominated, substantial discrepancies occurred. Other inaccuracies are produced by the way the model worked. It did not account for smaller- than-median gaps which were acceptable to some drivers, and larger-than-median gaps which were acceptable to nearly all drivers. An advantage of this type of model is that it is simple to adjust the gap acceptance, a deterministic relation, to compensate for simplifications in the probability of overtaking gaps.

4.1.3 The Unified Model

The Unified Model proposed by Werner and Morrall (1984) defined the level of service in terms of the demand and supply of overtaking opportunities. This is more in line with how a driver perceives the level of service of a two-lane rural road. The model gave the designer the ability to quantify the interactions of two opposing streams of traffic.

Supply was a function of the number of gaps larger than 30 seconds in the traffic stream, the available passing sight distance and provision of passing lanes. The percentage of time that a gap occurred in the opposing traffic stream was calculated with a negative exponential distribution.

The demand function was based on the catch-up rate per kilometre. Wardrop's formula for predicting overtaking demand (Morrall et al.) was used which required the mean and standard deviations of speeds for the section in question. Thus the designer had a simple way of calculating the demand for overtaking and the supply of overtaking opportunities. The relative sizes of these figures showed whether or not platoons formed faster than they dispersed.

The percentage of platooned vehicles is commonly used as a basis for determining level of service on a two-lane rural highway. The need for passing lanes is determined by the overall passing opportunity on the highway. It is recommended that the overall passing opportunity should be 50 % of the road section length. The hourly design traffic flow of the section is used to calculate the supply and demand components of the available passing opportunity.

Morrall has recommended refinement of the Unified model with the collection of field measurements under a wide range of volumes and directional splits. This could be combined with TRARR analysis to improve the specification of the supply and demand functions.

The Unified Model makes no attempt to recommend the locations or lengths of passing lanes which FHWA (1987) and Hoban (1981) have shown to be important determinants in the effectiveness of passing lanes. Alberta Transportation, the prime user of the Unified Model, sets no standards in terms of length and spacing of passing lanes. But it does provide general guidelines such as "space (passing lanes) at appropriate intervals to relieve driver's frustration" and "experience in Alberta suggests that long passing lanes do not provide a good return in terms of number of passes made over the two kilometre mark".

4.2 Computer Models

Computer models are useful as they enable use of models governed by the laws of probability to describe driver behaviour. They also allow full control over the variables which provides a distinct advantage over field measurements. Because of the large number of variables that are governed by probability, rural two-lane roads are well suited to computer modelling (Pursula and Siimes, 1993). These benefits are tempered with several disadvantages. The first of these is doubt about the ability of the model to replicate real world results. The statistical variation of the results is another concern. These problems can be overcome with careful calibration and validation but in general, traffic simulations are expensive and should only be performed when it is economically justifiable. Kawczynski (1994) goes further to suggest that comprehensive traffic data collection is several times cheaper than simulation. However data collection may not provide sufficient data over the desirable ranges of all variables, nor can it be used for "new" situations.

A notable feature of the studies reviewed has been the use of calibrated simulation models to test situations for which field measures may not be available in sufficient quantity to allow consideration of each factor in turn. The two most commonly referenced models are TRARR and TWOPAS.

4.2.1 TRARR (TRAffic on Rural Roads)

TRARR was developed by the Australian Road Research Board (now known as ARRB Transport Research Ltd). It is a microscopic, stochastic model that can simulate uninterrupted traffic flow on two-lane two-way highways with or without auxiliary lanes. The model operates on a time scanning basis to update the movements of individual vehicles within the traffic stream.

4.2.1.1 Experiments with TRARR

Pursula and Siimes (1993) used the TRARR model to evaluate differences between high class two lane roads and rural three lane roads in Finland. The calibration process began with altering the vehicle composition of the traffic flow to match the Finnish case. Desired speeds were then changed in accordance with measured data. It took some trial and error to achieve satisfactory results. The high class two-lane road in Finland has a wide shoulder that is used for passing. This, coupled with differences in driver behaviour between Finland and Australia, lead to underestimates of overtaking rates. This was corrected by adjusting an overtaking safety factor. Good results were then obtained.

This example shows how TRARR can be applied to situations different from those for which it was primarily designed. TRARR was also used for runs to simulate the efficiency of a 22 kilometre length of three lane road. The results obtained were close to those measured in the field. There were parts of the output that were not in close agreement but this was explained by the presence of rest areas and service stations and the fact that at very heavy flows people tend to overtake less because there is little to gain from doing so. TRARR does not account for this behaviour.

Smith et al. (Unpublished) demonstrated that TRARR could be used to develop a system of passing lanes that ensured a minimum level of service was maintained. This has also been achieved by Morrall et al. (Undated) who used TRARR to design and evaluate a programme of passing lanes and slow vehicle turnouts in California.

Wolhunter et al. (1988) used TRARR to establish a delay based warrant for climbing lanes. The model was calibrated and then run to establish the effect of gradient on space mean speed. Decrease in this speed formed the basis of delay calculations which were subsequently used to construct the model ANDOG (see section 5.2.6 below).

4.2.1.2 Criticism of TRARR

Kawczynski (1994) criticised the use of TRARR in British Columbia. The criticism was based on the difference between volume/speed relationships established by TRARR simulation and used in highway design, and the results of speed surveys carried out in various locations in British Columbia. The author claimed that TRARR was based on outdated principles. The main one of these was that the ratio of vehicle horsepower to weight would determine the speed. This assumption was challenged in the light of modern cars being lighter and more powerful than those of earlier eras. The behaviour of the driver was much more of a determinant of speed today than the power to weight ratio. Also questioned was the interpretation of results.

One of the key results in the North American context is the critical headway, defined as the headway at which the following vehicle is said to be interacting with and delayed by the leading vehicle. This affects the percentage of vehicles in platoons, which is one of the main determinants of level of service. Level of service is relied upon in the development of passing lane strategies. The result of a large critical headway is that many highways appear to provide a lower level of service than may actually be the case.

It should be noted that since the spot volume/speed relationships established by Kawczynski cover small ranges of AADT his conclusions must be used with caution.

4.2.1.3 Downhill gradients

TRARR does not account for the effect of long, steep downhill gradients on traffic operations (Archilla and Morrall 1995). Archilla and Morrall experimented with incorporating the World Bank Micro-Transitional Model into TRARR. This would allow TRARR to predict the speed of vehicles on sustained downgrades. They decided to use the road speed index within TRARR to model speed changes on downgrades. To allow this, the size of the speed multiplier table in TRARR was increased. They concluded that the World Bank model complemented TRARR well and TRARR was able to predict the traffic flows at the bottom of grades with satisfactory accuracy.

However discrepancies in the standard deviations for speed were unacceptable. Overall the study showed the adaptability of TRARR and the results are another validation of the model.

4.2.1.4 Future development

Lovell et al. (1994) describes the development of a new user interface for TRARR and some new developments in the program itself. The more important proposed changes are listed below:

- Graphics based input;
- Internal validity checks on input;
- Choice of metric or imperial units;
- Choice of right or left hand drive;
- Ability to save and retrieve data sets;
- Ability to use USA or Australian vehicle classifications;
- Context-sensitive help;
- Increased traffic flow observation points; and
- Graphics based output.

Lovell et al. suggested that the improvements would allow easier use by North American traffic engineers and ensure the continued use of this widely used package.

4.2.2 TWOWAF

Kaub et al. (1988) report on the use of the TWOWAF model to simulate traffic flow conditions both with and without passing lanes. The TWOWAF model could not directly simulate the passing lane configuration, so an approximation was used where opposing vehicles were removed at sections where passing lanes were being considered. A revision of TWOWAF was undertaken to allow consideration of passing lanes and the resulting model TWOPAS has been used extensively in the USA.

4.2.3 TWOPAS

TWOPAS is a microscopic, stochastic model that can simulate uninterrupted traffic flow on two-lane two-way highways with or without auxiliary lanes. It was developed at the Midwest Research Institute in the USA specifically to simulate traffic operations on two-lane rural highways. The model operates on a time scanning basis to update vehicle movements.

4.2.3.1 Use of TWOPAS

Taylor and Jain (1991) selected TWOPAS to simulate the passing manoeuvre on rural two-lane two-way roads in Michigan. They successfully used field measurements of headway, speed and traffic composition to calibrate the model. The sensitivity of delay to various parameters was also tested. The cost of delay was used in the development of warrants for passing lanes. The following data was required for input:

- Entering traffic data;
- Geometric data;
- Traffic control data;
- Vehicle characteristics; and
- Driver characteristics.

All vehicles included in the mix had performance capabilities defined. For trucks and buses it was also necessary to define the weight/net horsepower ratio, weight/projected frontal area and factors correcting horsepower and aerodynamic drag for local elevation. For cars the maximum acceleration at maximum available horsepower and limitations on the use of maximum horsepower were considered. The default values in the program are American.

The mean and standard deviation of desired speed were also required, along with driver characteristics defined in terms of car-following sensitivity factor.

The model gives output data for specified locations along the roadway.

4.2.4 Comparison of TRARR and TWOPAS

Botha et al. (1993) compared the merits of TWOPAS and TRARR for simulating traffic on two-lane highways with low design speeds. They compared the models' major features, and found that they were similar as far as input was concerned, however, there were differences:

- Horizontal alignment was directly input to TWOPAS but horizontal alignment was input to TRARR using a "road speed index";

- Alignment specification was different. TRARR broke the road into equal units whereas TWOPAS used horizontal curves and grades. This made changing TRARR variables more awkward; and

- TWOPAS had 13 vehicle types, TRARR had 18.

Standard TWOPAS output was much more extensive than TRARR but could be cumbersome when only a few details were required. Additional output could be printed from both packages. Documentation was found to be similar but American terms in TWOPAS were different from the Australian terms used in TRARR. TWOPAS usually took longer to run because it is a larger program. Botha et al. decided that TWOPAS was easier to use because of difficulty in changing the geometric alignment in TRARR.

Two study sites in Northern California were selected and field measurements taken. One site was in level terrain and one in rolling terrain. Both sites were on 80 kilometres per hour design speed roads. Models were calibrated with data from one site and validated with data from the other. The measures used to test the output of the models were:

- Travel times in both directions (the primary measure for calibration);

- Percent Time Delayed as measured by the model; and

- Percent Time Delayed as measured in the field.

They found that during both calibration and validation phases the output from TWOPAS was closer to field measurements than the output from TRARR. TRARR tended to overestimate Percent Time Delayed. TWOPAS both underestimated and overestimated Percent Time Delayed but was closer to the field value than TRARR. For both models the Percent Time Delayed results over space were closer to field measurements than the Percent Time Delayed measured at a point. It is possible that a change to the headway value used to define a platoon would address some of these issues.

The authors decided that further development of the models was necessary before they could be applied without reservation. TWOPAS had the advantage from the American point of view that it generated the basic values used in the HCM for level of service and capacity analysis. Their overall recommendation was a tentative call for the adoption of TWOPAS for the analysis of two-lane roads in the USA.

Staba et al. (1991) also compared TRARR and TWOPAS and found that the results were similar. They selected TRARR as their preferred package, citing three primary reasons:

- It required less resources to develop input files for TRARR;

- TRARR run time was less; and

- TRARR output was in an immediately useable form.

4.2.5 ROADSIM Based Model

Kaub (Undated) presented a model to estimate the benefits of volume-generated passing lanes on two-lane, two-way rural roads. The model estimated the microscopic safety, delay and running cost benefits to produce a Benefit/Cost ratio along with cost-effectiveness estimates to assess construction options. The program used either default or user input hourly volume-based speed and delay models. Safety benefits were estimated using a statistical probability conflict opportunity/cost model. Overall economic assessment was via peak and off-peak, weekday and weekend, and monthly volume characteristics. The program was also able to estimate the length of passing lanes needed. The operational delay and running cost benefit aspects of the model were done using algorithms from the ROADSIM model.

The original ROADSIM model had a number of failings including the inability to input more than one set of traffic flow data at a time, the inability to model safety aspects of passing lanes and a suspected unrealistic modelling of passing occurrences. These were addressed by incorporating ROADSIM routines as subroutines that change the traffic volumes and summarise the weekly, monthly and annual benefits for each flow profile. Safety benefits were assessed using a unique Statistical Conflict Opportunity Accident/Cost Estimator to model accident benefits as a function of user-defined accident-related variables. The conclusion of the report was that the volume generated Auxiliary Passing Lane Economic Program was a useful tool in analysis of two-lane two-way rural and suburban roads.

4.2.6 ANDOG (ANalysis of Delays On Grades)

ANDOG is a program designed to provide a measure of the travel time savings from climbing lanes in mountainous terrain. It uses the difference between desired and actual speeds and the probability of delay calculated from equations derived from 1625 TRARR runs. The variables used to calculate vehicle speed are gradient, vehicle flow, directional split, percentage trucks and the percentage of trucks that are semi-trailers. Delays are calculated from two minute runs that use Poisson distribution to calculate flow. A relationship between ranked hourly flow, the independent variables, AADT and a peaking factor is used to calculate delay over one year, and the increasing AADTs are used to find delays in subsequent years. Finally delays are calculated over the design life of the lane discounted at a user defined rate and the present value of the benefits found. This allows comparison with the cost of construction to find the Benefit/Cost ratio.

4.2.7 CLIM (Climbing Lanes In Mountainous terrain)

CLIM enables designers to evaluate the effectiveness of short climbing lanes on average travel speeds. The program divides a road into three types of sections. These are:

- Sections with auxiliary climbing lanes;

- Two-lane sections with adequate passing sight distance; and

- No-passing sections.

Flow is generated by a translated negative exponential random number generator. Traffic is split into cars and trucks, by a uniform distribution, and allocated free speeds according to a normally distributed random scheme. Traffic is assumed to travel at this free speed unless it encounters a slow vehicle. The only impediment to a vehicle travelling at its free speed is when it catches up to a slower vehicle and is unable to pass it.

The program performs two basic functions. At the beginning of a road section where passing is permitted, all vehicle arrival times are calculated, with adjustments made if any are less than 1.5 seconds after the vehicle which started directly before it. When a platoon enters a road section where passing is permitted, all vehicles following a slower vehicle are considered for overtaking, based on a difference in free flow speed, length of overtaking available and, if there is no passing lane, the availability of a gap in the oncoming traffic stream. After overtaking has finished, the process moves to the next overtaking site where it is repeated. The model can then be run again with any proposed improvements and the difference in travel times taken as the decrease in delay. The travel time savings will be unique to a specific traffic volume and composition. The model has been validated with data collected at three sites and against a microscopic simulation program. The validation showed that the results were realistic.

Although stochastic CLIM is not a micro simulation program and so does not use excessive computer time. This allows a number of runs to be undertaken in order to obtain a reasonable mean value.

4.2.8 The N.C.S.U. Model

Khasnabis (1986) reported on an aspect of the output of the N.C.S.U. model (Developed by the Civil Engineering Department of North Carolina State University). He presented the results of a sensitivity analysis where percentage trucks and the percentage of the roadway where passing was prohibited were changed. Although the model was not calibrated with field measurements, the trends were clear and reasonable, leading to the conclusion that simulation techniques appeared to be a way of assessing operational impact of increased truck traffic as well as altered roadway geometrics. He went on to raise the possibility of quantifying some of these impacts with a properly calibrated model. The trends shown by the model were:

- Increased truck flows lowered the mean speed for a roadway length;

- With a given percentage of no overtaking markings, pass attempts per kilometre increase with truck traffic;

- Number of passes per kilometre decreased as the proportion of the road with passing opportunity increased;

- Number of passes per kilometre increased with increasing truck traffic;

- The number of vehicles passed per hour per kilometre increased with percentage trucks when less than 50 % of the road had passing opportunity; and

- For all truck percentages increasing passing opportunity resulted in decreased delay.

4.3 Summary of Models

Eight models have been identified in the literature reviewed. Although detailed descriptions of some have not been located these models may be initially classified into three groups:

- Micro Simulation Models (TRARR, TWOWAF, TWOPAS and N.C.S.U.);

- Analytical Models (CLIM); and

- Simplified Models (ANDOG, UNIFIED MODEL and PASSING OPPORTUNITIES MODEL).

Of these the simulation models TRARR and TWOPAS have been the most frequently tested and used in the determination of guidelines and strategies for the provision of passing lanes.

It is recognised that the use of simulation is an expensive exercise. There is a general consensus among authors of literature reviewed that micro simulation models provide the most appropriate tools for research into passing opportunities with the exception of Kawczynski (1994) as discussed in section 5.2.1.2. In all cases some doubts about performance and calibration have been expressed.

5 IMPORTANT FACTORS FOR THE DEVELOPMENT OF GUIDELINES

Although the findings of a number of studies into the effectiveness of passing improvements are presented, it should be noted that the translation of these into standards is limited. The exception is *Low-Cost Methods For Improving Traffic Operations On Two-Lane Roads* FHWA (1987), which in its own right summaries much of the literature related to the design of passing improvements. The publication does not specify standards as such but provides discussions and recommendations of good practice. It is a key reference and most of the findings outlined below relate to more recent studies.

5.1 Location of Passing Opportunities

A number of studies have sought to identify the key issues that influence the location of passing opportunities.

Khan et al. (1991) found that the percentage of vehicles in platoons was about the same for level and rolling terrain, but average speed was lower in rolling terrain.

They also concluded that:

- The percentage of roadway length where passing was prohibited had an appreciable effect on the percentage of vehicles in platoons; and

- While the percentage trucks and recreational vehicles had a greater impact on grades than in level or rolling terrain, trucks caused more platooning on roads without passing lanes; whereas recreational vehicles appeared to have a higher effect on speed and platooning on sections with passing lanes.

Jain and Taylor (1991) used the TWOPAS model to perform sensitivity analyses on the benefits of passing lanes on two-lane two-way highways. They found that the frequency of vertical curves did not significantly affect cost savings. They also found that the benefits depended on the grade.
The percentage of roadway where passing was prohibited was found to be insignificant in terms of user benefits from passing lanes. The percentage of trucks in the traffic stream was found to become significant at "higher volumes" (the range of AADTs used was 10 000-20 000 vehicles per day). From their work, they were able to conclude that in terrain incorporating undulating steep grades, passing lanes did not significantly reduce delay.

5.2 Traffic Volumes

May (1991) claimed some general conclusions for the shorter passing lane sites in rolling to level terrain that he observed. These were

- Overtaking numbers on passing lanes were negligible when 5 minute hourly flow was less than 120 vehicles per hour;

- The ratio of passes to vehicles increased from about 30 to 50 % as 5 minute hourly flow rose from 200 to 400 v/h; and
- The ratio of passes to vehicles was about 50 % when 5 minute hourly flow was between 400-600 v/h.

Khan et al. (1991) found that platooning was very sensitive to volume. Volume was the most important variable in determining the percent of traffic following in platoons and average speed.

5.3 Length of Passing Opportunity

5.3.1 Effectiveness

May (1991) found that effectiveness of the passing lanes was dependent on the length of passing opportunity. This arose from sensitivity analyses using TRARR runs where the length of passing lane was the only variable. Lanes between 400 and 1200 metres long were found to be most effective in terms of number of passes per unit length of passing lane and reduction in Percent Time Delayed per kilometre length of passing lane. The study also found that the sites located in rolling and mountainous terrain saved the most amount of annual travel time per length of passing lane. In level terrain the highest savings of annual travel time was achieved using a 1300 metre lane. All sites were carefully calibrated with measured field data before these sensitivity analyses were undertaken, but the use of such a small sample of sites must be questioned.

The same study assessed the user benefits at five sites, taking field measurements at the beginning and end of the passing lanes. These measurements were used to calculate performance measures including percent time delay, time headway distribution and platoon size distribution. The results showed that there was no user benefit with the short passing lane in level terrain, slight benefits with the short passing lane in rolling terrain and slight benefits with the medium passing lane in rolling terrain. Although the site had low vehicle flows, the longer passing lane in mountainous terrain was the only site to show significant user benefits.

Pursula and Siimes (1993) used a locally calibrated TRARR model to analyse an experimental three-lane road in Finland. They analysed one pair of passing lanes, one in each direction, to determine the effects on traffic flow. Their measurement for effectiveness was the number of passes per kilometre of passing lane. They found that the length at which a passing lane was most effective was dependent on the flow. The directional splits for the different flow rates were varied according to values measured in the field. They concluded that lengths of 1.0 kilometre on modest flow levels, 1.5 kilometres on medium and 2.0 kilometres on the heaviest flows were most efficient. However, the efficiency was reasonably constant from about 1.0 to 2.5 kilometres. The next step was to change the measurement of effectiveness to travel time in both directions. Again optimum length increased with flow. The range of length at which the lanes were most effective was 1.0 to 2.5 kilometres.

Khan et al. (1991) found that longer passing lanes had a bigger effect on reducing platoons than short lanes. However, in terms of net benefits, a 1-2 kilometre lane was more effective than a 3 kilometre lane.

5.3.2 Safety

Passing opportunity in lower volume situations is usually left to the availability of sight distance. Standards in the USA are set down in the Manual of Uniform Traffic Control Devices (MUTCD) and AASHTO also provide guidelines. The fact that these guidelines are significantly different has prompted some researchers to test their adequacy. They have found that with modern high speed passing manoeuvres, many older standards are insufficient.

Gordon et al. (1984) found that demographic changes in the driving population and vehicle improvements since the 1960s meant that passing sight distance was outdated.

The MUTCD specifies the minimum length of road where it was legal to pass to be 250 metres regardless of speed. Weaver and Glennon (Undated) cite limited studies which showed drivers would not complete a pass even within a 250 metre section. Many drivers would reach the critical position, defined as the point at which completing or aborting the manoeuvre would require the same time in the opposing lane, at a point where sight distance was less than the minimum. Khasnabis (1986) showed that the MUTCD practice for marking no-overtaking lines did not provide safe distance for truck passing. This was in agreement with Harwood et al. (1989) who researched sight requirements for various vehicles to overtake. They found that current MUTCD values were good for car passing car, but that the required sight distance increased for car passing truck, truck passing car and truck passing truck. They reported disagreement about which distance was the most reasonable basis for design. All values were shorter than those provided by AASHTO which were considered conservative.

Ohene et al. (1988) analysed the passing manoeuvre and concluded that MUTCD sight distances were inadequate at speeds greater than 50 kilometres per hour and became increasingly inadequate at higher speeds. The MUTCD values only became acceptable at very high rates of acceleration and deceleration.

Polus and Tomecki (1987) agree with the work of Harwood et al. (1989). They took field measurements that showed AASHTO values were conservative and should be reviewed.

Lieberman (1982) presented a model for calculating safe passing distances on two lane rural roads. This model showed that the sight distances specified by AASHTO may be inadequate from a safety standpoint. The model determined safe passing sight distance from the time it took to finish the manoeuvre from the critical position and the time it took to get to the critical position. The study concluded that the sight distances may need to be amended in the light of faster impeder speed and the number of trucks and sub-compact cars in the modern traffic stream.

Proudlove (1990) showed that there was inconsistency between countries in the standards for safe passing sight distance. Australian distances were generally the longest, followed by Canada and the USA. Britain had the smallest sight distance requirements. These differences were found to be small when like situations were compared.

In summary safety concerns have been raised over the length of passing opportunities specified in some standards although in each case these values of concern appear less than those specified in the AUSTROADS (1989) guidelines adopted for use in New Zealand.

6 SUMMARY

The literature review has outlined the approaches used overseas and identifies a number of key issues:

- That frequent and effective passing opportunities are important for the operation of two-lane rural roads with two-way traffic flow in excess of 500 vehicles per hour, minimising both the time lost and the risks taken by frustrated drivers attempting to pass;

- Although passing accidents are a small proportion of the entire accident record the severity of passing accidents is higher than the average for all accidents. It appears that the rate of passing accidents can be significantly reduced by the addition of passing lanes although the range of decrease varies widely from 5% to 38%;

- The underlying form of overseas studies into passing improvements is to identify the need on the basis of warrants or guidelines that are based primarily on level-of-service criteria. It is noted that the form and definition of the effectiveness measures have a major impact on the identification and ranking of need. For this reason such measures must be linked to user perceptions;

- The application of such level-of-service criteria does not readily allow consideration of the effectiveness of an improvement nor consideration of the cost implications. Furthermore such approaches are not available for alternative improvements such as turn-outs, slow vehicle bays, or wide shoulder treatments;

- While a number of studies investigated issues related to the provision of passing facilities, such as optimum passing lane length, location, spacing, travel time and the distance over which benefits are obtained, no definitive rules are available to quantify the benefits that will result. It appears that while the general recommendations of good practice may be used to select options for consideration, the benefits are generally derived from more detailed analysis; and

- It appears that the assessment of economic benefits generally requires the use of a computer model, and given the complexity of the problem, micro simulation is generally favoured. Of these the two most commonly used programs are TRARR and TWOPAS. These models are similar, and comparative studies suggest ease of use is the criteria that determines a preference for one model or the other.

7 CONCLUSIONS

1. There is a need to research criteria that can be easily calculated or measured on site to express users' perception of the level of service related to passing opportunities provided by the roads in New Zealand. Such criteria could then be used on a network-wide basis to identify the need for improvements and provide a means of assessing client (road user) satisfaction.

2. Although it is unlikely that the warrants or guidelines developed overseas could be applied directly in New Zealand, the following aspects have important effects on passing behaviour and should be considered when developing guidelines for New Zealand:

   - Driver Frustration
     Aborted passing manoeuvres may be used as a measure of driver frustration which has major implications for safety.

   - Percentage of Road Length with Passing Opportunity
     Given changes in vehicle performance, research is required into the sight distance necessary for overtaking.

   - Traffic Flow
     Traffic flow is strongly related to the percentage of vehicles in platoons. Two way flows of 500 vph may be a useful threshold for assessing the need for increasing passing opportunities.

   - Length of Passing Lanes
     The effectiveness of passing lanes depends upon the length and the measure of effectiveness that is used. Passing lanes in the range of 800 to 1500 metres are most effective for most of the measures reviewed.

   - Road Gradient
     Road gradient is an important variable especially when heavy vehicles form a high percentage of the traffic flow. Measures for determining the effect of gradient on passing can include the steepness of the grade, or the effect that the gradient has on speed differentials.

   - Percentage of Heavy Vehicles
     This becomes more crucial as the traffic flow and road gradient increase.

3. The prediction of benefits for inclusion in the economic evaluation of passing opportunities requires use of a computer-based model and the

most appropriate candidate for New Zealand is TRARR developed by the Australian Road Research Board (now ARRB Transport Research Ltd).

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