

Assessment of Rural Road Simulation Modelling Tools

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Executive Summary

This research investigated the relative merits of a number of different simulation packages for modelling vehicle interactions on rural highways. A review was also made of models of rural crash risks and their application in New Zealand was considered. The main objectives of the research, carried out in 2001/02, were:

- To identify suitable software packages for rural road simulation and assess their features.
- To compare the performance of different packages in assessing vehicle speed prediction, vehicle interaction, and relative crash risks.
- To consider the potential future application of such packages in New Zealand.

Survey Scoping and Site Selection

A review of local and international literature on relevant topics revealed:

- Horizontal and vertical alignments have the greatest influences on driver speed selection and therefore need to be modelled with some precision.
- Estimation of undesired vehicle-following and congestion delays is another important use of modelling, and is affected by traffic volume and composition, available passing sight distance, and traffic speed distributions.
- Predicting speed changes due to roadside development and changes in speed limits is particularly difficult, and site-specific measurements are recommended.
- Narrow road widths do not appear to have as much influence on vehicle operations as other factors, particularly for modelling on State Highways. Other features that can affect modelling of highway traffic, both in terms of delays and safety problems, include side roads, one-lane bridges, and roadworks with traffic control.
- Most simulation models developed to date have been designed specifically for evaluation of efficiency issues (e.g. travel time savings and reductions in time spent following) rather than assessment of safety benefits. Analysis of both within the same package would be preferable for project development purposes.
- At present, most detailed rural simulation in New Zealand is carried out using TRARR (ARRB Transport Research, Australia). However a number of existing concerns and limitations have been identified with this package, and no further upgrading is planned.
- TWOPAS 98 (FHWA, US) is a similar tool and current ongoing development makes it an attractive long-term proposition. However, its appropriateness and practicality for New Zealand use needs to be confirmed.
- Network micro-simulation packages like PARAMICS 2001 (SIAS, Scotland), commonly used for urban and motorway modelling, may also have the potential for rural simulation, subject to appropriate underlying driver behaviour models.
- A desirable rural road model for New Zealand project evaluation should be able to take in a range of road, environment, traffic, vehicle and driver attributes and accurately predict vehicle speeds, running costs, crash risk, emissions, and driver comfort.
- A practical model ideally requires a number of other "efficiency" features, such as an intuitive graphical interface, easy creation/editing of input data, incorporation of field data, customised outputs for project evaluation, and good documentation.
- Incorporation of road-modelling features into existing road design packages could enable built-in assessment of designs in terms of road user benefits and costs, resulting in more immediate feedback on the most optimal designs.

From these findings, a survey plan (sites, methodologies) was developed to enable collection of suitable field data for assessment of the various simulation models.

Field Data Collection and Simulation

Following field surveys at over 20 rural highway locations, subsequent analysis and modelling showed:

- While some project types (e.g. passing lanes) are well served by modelling tools, others are still not well supported. There may be scope for further research to develop suitable analysis tools for the industry.
- Each of the three main models investigated appears to have particular strengths over the others when considering different project applications, and therefore have a part to play in New Zealand rural modelling.
- TRARR still has a significant advantage in terms of familiarity to many New Zealand practitioners, and well-established support tools to enhance its use for project evaluation.
- TWOPAS generally has modelling features at least as comprehensive as TRARR. However at the moment it is limited when bringing in road alignment data automatically. The forthcoming update of TWOPAS offers more promise.
- PARAMICS provides considerable flexibility to model non-traditional rural simulation situations, however it is more difficult to quickly set up. The applicability of the model's underlying theory to rural New Zealand roads is also unclear.
- There are existing usability and software problems with both TWOPAS and PARAMICS that need to be addressed in future versions to make them more practical for rural highway use in New Zealand.

From these findings, an initial ranking of suitability for different project types was produced.

Review of IHSDM and Related Safety Models

A review of local and international rural crash risk modelling revealed:

- Most existing crash analysis procedures are "static" models, i.e. they predict crash numbers by combining typical crash rates for a certain facility, traffic volumes, and maybe additional site-specific modifying factors.
- Micro-simulation could be used to observe traffic "conflict" events and assess likely crash rates. The application of this approach to mid-block situations is still relatively untapped, particularly where the measured conflicts are fairly rare.
- On rural routes, road features (e.g. curvature, roadside hazards, sight distance) are more important in determining crash likelihood and severity, whereas urban drivers are usually more constrained by either speed limits or other road users.
- Research has found increasing crash risks related to increases in horizontal curvature and absolute gradient as well as reductions in available sight distance.
- Higher mean speeds, speed variances, and speed environment differences increase crash rates and severities. An accurate means of predicting vehicle speeds is therefore necessary.
- Interactive Highway Safety Design Model (FHWA, US) is a suite of tools for assessing the safety impacts of design decisions on two-lane rural highways. Its use in New Zealand, using local design standards, is a promising approach although considerable road design data is required for input.
- Other potentially relevant road safety models recently developed internationally include SafeNET (TRL, UK), Road Safety Risk Manager (ARRB, Australia), and TARVA (FinnRA, Finland). Many would probably require some adjustment to their parameters to give suitable estimates in New Zealand.

- Some road safety models examined could provide a reasonable estimate for New Zealand of the relative change in crashes between two situations, but not absolute crash prediction, due to roading, social and legislative environment differences.
- Inclusion of actual historical crash data should greatly help adjust crash predictions for local effects that are otherwise difficult to account for, and should allow a relatively simple but effective model to be developed and used fairly quickly.
- In New Zealand, typical rural crash rates are available for broad terrain/volume categories, as well as predicted crash changes for specific treatments, curve speeds, and different cross-section attributes. However there is little specific guidance on how combined roading changes might be dealt with, or the effect on different crash types.
- New Zealand's relatively well-integrated systems for collating highway and crash data provide valuable sources of data on the effectiveness of various road safety treatments. These advantages should be maximised in both developing and using any crash models here, with detailed on-site data collection where required.
- Head-on/lost-control curve crashes curves comprise 49% of all reported rural two-lane crashes in New Zealand, followed by similar crashes on straights (21%). Less common are rear-end/obstruction (11%), intersection (9%) and overtaking (8%) crashes, although they play a much greater role on three/four-lane highways.
- Rural crash models that are more sophisticated than the existing evaluation procedures in New Zealand may be required to identify the often minor effects of changing small aspects of roading design for incremental safety improvements.

Recommendations

The following items are recommended for further investigation or action:

- Undertake further examination of the potential for incorporating safety assessment into future development of existing "travel efficiency" simulation models.
- Undertake further surveys as described in the survey plan to further validate the accuracy of the various simulation tools, particularly "before and after" surveys.
- Encourage the use of different simulation packages on rural roading projects, particularly those more suited to a certain application, to obtain the most appropriate project evaluation and to develop experience by practitioners.
- Arrange technical workshops introducing the various modelling options to practitioners, and providing guidance on how to use them for various applications.
- Continue to monitor developments in models such as TWOPAS and PARAMICS, and trial them further in New Zealand on suitable rural highway projects.
- Where possible, investigate further the suitability of other potential simulation models identified overseas such as HUTSIM, VTI, AIMSUN, and DRACULA.
- Continue to monitor the development of IHSDM and trial its use in New Zealand. Also keep track of other applicable overseas road safety models.
- Scope the required needs for road safety models in New Zealand at various levels (national/regional strategies, project option scoping, detailed project design, highway audit).
- Focus rural crash model research in New Zealand initially on curve-related crashes, with more sophisticated development of other crash types later.
- Identify key unsafe driving actions in New Zealand from an analysis of crash report information and observe their prevalence in the normal driving population.

- Undertake statistical analysis of the relative correlation between crash numbers and potential key indicators of safety, such as mean/percentile travel speeds, sight distances, vehicle lane positions, and overtaking/intersection manoeuvres/conflicts.
- Investigate integrating rural road safety models and other road user benefits to existing road design packages, enabling faster specification of road layouts for project assessment.

Abstract

This research investigated the relative merits of various simulation packages (in particular TRARR, TWOPAS and PARAMICS) for modelling vehicle interactions on rural highways. It assessed their suitability for use as tools for evaluating crash risk and travel efficiency, particularly in the prediction of vehicle speeds and bunching in typical highway situations. All were found to have some strengths over the others for particular project applications. A review was also made of recent or developing models of rural crash risks (including IHSDM) and their potential application in New Zealand considered. Although the underlying methodologies appear promising, most would require further adaptation for the New Zealand environment.

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1. Introduction

This research investigates the relative merits of a number of different simulation packages for modelling vehicle interactions on rural highways. The research was carried out in New Zealand during 2001-02. It assessed their suitability for use as tools for evaluations of crash risk and travel efficiency. A review was also made of recent or developing models of rural crash risks, particularly those incorporating simulation techniques, and their application in New Zealand was considered.

1.1 Background

New Zealand relies largely on two-lane rural highways for its inter-regional land transport network. Many of these highways are less than optimal when considering consistency of speed environment, safety hazards, and minimisation of delays. To counter this, various ongoing improvements have been investigated and constructed, including realignments, passing-lanes, black-spot removal, and four-laning.

Previous research in New Zealand (detailed later in this report) has focused on small elements of the overall rural roading picture, such as free speeds as a function of road alignment, efficiency and safety benefits of passing opportunities, and the relationship between crashes and road geometry. There is a need to consider the overall impacts of changes to road alignments and cross-sections for both safety and efficiency in a unified manner.

To assist in prioritising funding for future upgrading work, detailed simulation modelling is required to firstly identify sections requiring improvement and secondly to determine the likely effect of improvement projects. There is currently little guidance for analysts on the most suitable simulation tools available to use, and how to use them appropriately for various projects. Although more simplified procedures are being introduced to replace some simulation work and to make things easier for both analysts and Transfund (e.g. passing lane procedures), there is still a need to validate such procedures, prior to their general usage.

A number of simulation packages are candidates for investigation. Most detailed rural simulation in New Zealand is currently carried out using TRARR (described in detail later). However, other options are beginning to look promising, such as alternative rural simulation packages (like TWOPAS) and more general micro-simulation software (like PARAMICS), and these are investigated further. The appropriateness of more simplified vehicle evaluation models, such as the 2000 HCM, are also worth investigating.

The simulation models described above are generally weak in the assessment of safety benefits, so alternative tools need to be reviewed in this area. A recent development in the US, the Interactive Highway Safety Design Model (IHSDM), is worthy of an investigation in New Zealand. Similarly, other models developed around the world may also be worth looking at.

1.2 Objectives

The main objectives of this research were:

- To identify suitable software packages for rural road simulation and assess their features.
- To compare the performance of different packages in assessing project evaluation measures, such as vehicle speed prediction, vehicle interaction, and relative crash risks.
- To consider the potential future application of such packages in New Zealand.

To meet these objectives, extensive literature was reviewed to identify the key performance measures of interest, and potentially suitable models available. Field survey data was then collected to provide relevant information for assessing various packages, and the results were analysed. For assessment of crash risk models, a separate search was made to identify promising evaluation tools. These are discussed in more detail below.

1.2.1 Task 1: Study Scoping and Site Selection

Task 1 had the following main sub-tasks:

- Determination of desirable key features of rural simulation models, both in terms of technical accuracy and model usability.
- Background literature review of technical theory underlying the features to be modelled
- Identification of potential modelling packages available and selection of models for investigation.
- Basic assessment of the selected packages in terms of desired features (i.e. the ability of the package to allow for them)
- Identification of information needed to compare actual field data with modelled outputs
- Development of survey plan (sites, methodologies) to collect required suitable data for testing models and validating them.

The outputs from this task were fed into Task 2 where the required field data was collected and equivalent simulation models were set up for comparison.

1.2.2 Task 2: Field Data Collection and Simulation

Task 2 had the following main sub-tasks:

- Undertaking field surveys to collect suitable traffic data
- Collation and analysis of collected data
- Development of highway models in simulation packages to replicate surveyed sites
- Comparison of results from different packages with the field data
- Assessment of simulation packages for ease of use, practicality, etc

From this analysis, conclusions were drawn as to the applicability of each model for New Zealand conditions.

1.2.3 Task 3: Review of IHSDM and Related Safety Models

Task 3 had the following main sub-tasks:

- Background literature review of safety-related models and similar research
- Review and assessment of documentation and software from IHSDM programme
- Assessment of other safety models identified elsewhere in the world
- Discussion of applications for safety models in New Zealand

The review considered what aspects of these models (and their underlying research) could be relevant here and what may need to be changed to make them suitable for use here.

1.3 Report Outline

Section 2 of this report summarises literature reviewed on rural highway modelling, and develops a survey plan.

Section 3 then details the results of site surveys on rural highways, data analysis, and modelling of the sites using simulation packages.

Section 4 reviews some road safety prediction models from around the world and assesses their usefulness in New Zealand.

Conclusions and recommendations from this report are in Sections 5 and 6, followed by a list of references and appendices.

2. Study Scoping and Site Selection

An assessment of simulation packages involves two main issues:

- The *technical* ability of each package to model a wide range of real-life situations with reasonable accuracy
- The *functional* ability of each package to enable relatively easy set-up, calibration, and production of results

Before proceeding further with our review of rural road models, these issues need to be explicitly defined. This section discusses these matters and identifies a methodology for proceeding.

Firstly the desired features for rural road simulation models were identified and background literature on these areas was reviewed. This report presents a range of possible simulation tools and describes their key attributes. The features of the proposed software tools were assessed and compared with regard to their general ability to model rural highways. Based on the desired features, a list of possible scenarios to test was finalised. To test these scenarios against actual vehicle/driver behaviour, suitable field surveys were identified for field data collection.

Having confirmed:

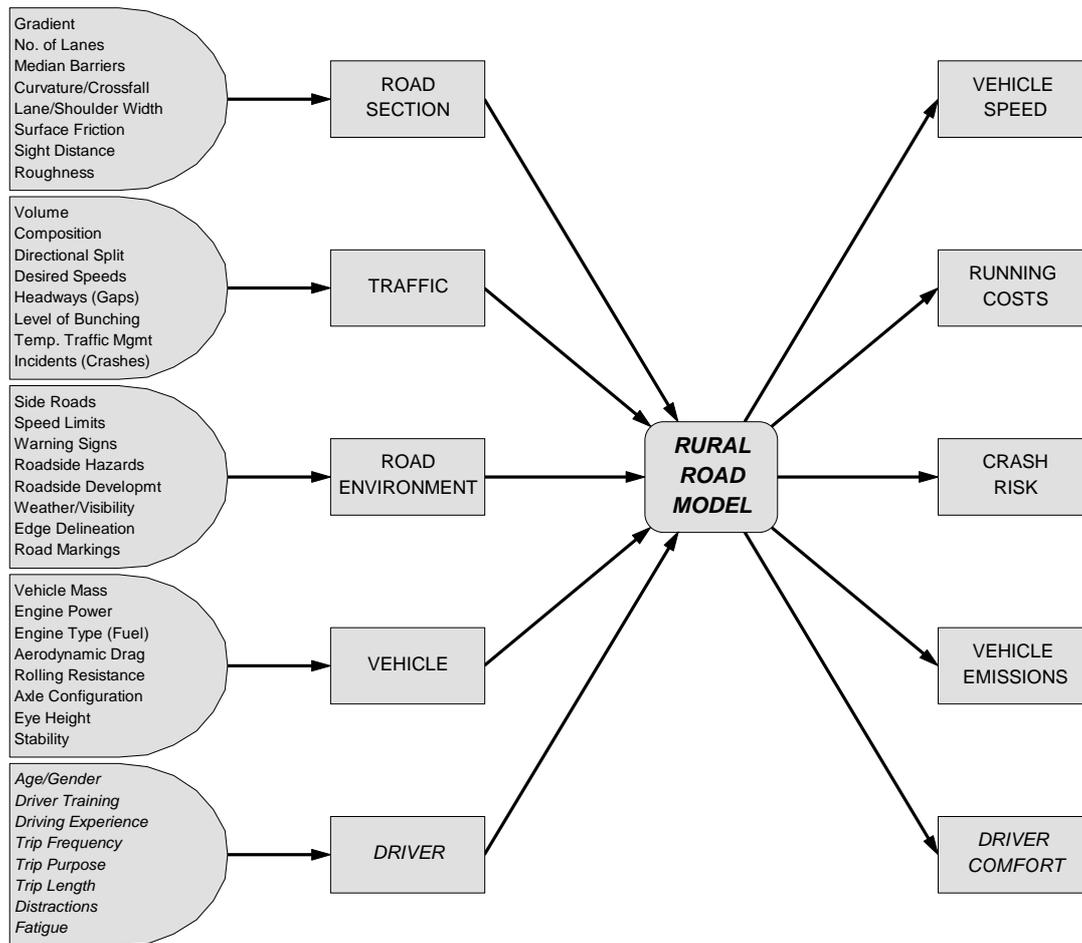
- which software packages would be used;
- which scenarios would be investigated; and
- which sites would be surveyed and modelled,

a project survey plan was then developed.

2.1 Desirable Key Features of Rural Simulation Models

Koorey & Gu (2001) developed a framework for future development of detailed rural simulation modelling. It identified key outputs desired from such models (largely in terms of project evaluation), and identified various input factors (such as road and traffic conditions) that could affect these outputs. Figure 2.1 provides an overview of the requirements that an ideal rural simulation model needs to take account of. The various inputs on the left-hand side, categorised for clarity, interact in various ways to produce the outputs on the right-hand side. Many of these factors will be examined in more detail in the literature review in Section 2.1.

Figure 2.1 Rural Road Modelling – Suggested Framework



The above framework provides an over-arching basis for specification of a model that provides all of the required information for project evaluation in New Zealand, using as wide a set of information as possible. The diagram does not indicate the relative importance of each input, and it may be that some inputs can be ignored without significant effect on the final results (or at least on some outputs). In practical terms, reduction of the input data (or certainly the accuracy of some of it) may be necessary to minimise the costs in obtaining the data. There is little point in an improved model if the required effort and cost of populating and calibrating it is excessive.

Some of the road and traffic factors may have influences in both the short and long term. For example, an isolated horizontal curve will affect driving speed at that site; however, a series of horizontal curves will also have an effect on the overall desired speed along a route. Similarly the presence of other traffic will affect the ability to overtake, but continuous traffic may also start to affect the gaps that drivers will accept for overtaking, if they become frustrated and take more risks.

While some of the relationships between various inputs and outputs are well established, it may be that further research is required to identify other relationships. Indeed, this is probably why some of these attributes do not currently feature in

existing models. This framework provides an initial starting point to help identify these “gaps” in knowledge.

While considering the merits of various simulation models, it is important to bear in mind the appropriateness of using such a model in the first place. The most recent version of the US Highway Capacity Manual (TRB 2000) contains some information on assessing simulation and other models. Amongst the shortcomings of simulation models listed, it includes the following.

- There may be easier ways to solve the problem.
- Simulation models require considerable input characteristics and data.
- Simulation models may require verification, calibration and validation.
- Some users may apply simulation models and not understand what they represent.
- Some users may not know or appreciate model limitations or assumptions.

It may be that, with the introduction of more simplified approaches (e.g. passing lane procedures), the use of modelling will become less common in specific project work. The level of accuracy gained from a simulation model may not justify the additional effort probably required to achieve it.

Although the simplified procedures make things easier for both analysts and Transfund, there is still a need to validate such procedures using more robust analyses, prior to their general usage. Modelling is likely to be able to continue to provide that validation. Therefore the development of more sophisticated future models may be more for policy and research work rather than for general use by practitioners. The exception may be for very large construction projects, where accuracy of results is important before committing to a significant amount of funding.

2.1.1 Practical Features of Simulation Models

As well as having the underlying theory sufficiently correct, a practical model for use in New Zealand and elsewhere ideally requires a number of other features to make it efficient to use. Koorey & Gu (2001) provided a list of desirable features including:

- Adequate capacity to model very long highways and very high traffic volumes.
- Ability to create or import road data using a number of formats, particularly using either fixed-interval (e.g. 10 m) or element-based geometry data.
- Easy editing of roadway information, particularly in relation to RCA route position systems.
- Ability to specify (or import) a range of time periods and traffic flow distributions/compositions.
- Ability to derive default or typical information where field data is not available (note: this approach needs to be treated with care).
- Identification, warning, and possibly correction of invalid value ranges.

- Customisation of outputs to produce desired information in specified format.
- Relating outputs to Transfund project evaluation benefits.
- Use of field data for more automatic and efficient calibration.
- Text-based input/output files for external editing if desired.
- Facility to change distributions used for some values (including using constant deterministic values).
- Ability to expand data requirements where desired (e.g. more vehicle types or longer road sections).
- A modern graphical interface (e.g. MS Windows or Unix X-Windows) that uses standard features (buttons, drop-down lists, etc).
- Ability to graphically display on plan and longitudinally the analysed routes and overlay various data sets (speeds, bunching, sight distances, etc).
- Adequate documentation (both on-line help and written).

It must be emphasised that, while a model with all of these features would greatly ease the workload for the user and assist with minimising data errors, this is of little consequence if the underlying model is not sufficiently robust.

2.2 Literature Review of Technical Theory

New Zealand relies largely on two-lane rural highways for its inter-regional land transport network. Many of these highways are less than optimal when considering consistency of speed environment and minimisation of delays. To counter this, various ongoing improvements have been investigated and constructed, including realignments, passing-lanes, black-spot removal, and four-laning. All of these projects require justification via analysis of the expected benefits, generally in terms of travel times, vehicle operating costs, crash savings, and reduced driver frustration (determined by willingness-to-pay).

The following discussion reviews some of the main factors that can affect the evaluation of a highway project, as previously published.

2.2.1 Road Alignment Effects

A prime concern when modelling is to understand the effect that a proposed alignment will have on driver speed selection. Bennett (1994) provided a comprehensive review and survey of free (unimpeded) speeds on rural two-lane highways in New Zealand. He identified horizontal curvature and vertical gradient as having the greatest influences on travelling speeds, and developed a speed prediction model that took these factors into account. The surrounding road environment (generally in terms of terrain and road type) was also important, as defined by measures such as "bendiness" (the average amount of horizontal curvature over a length of road) and approach speeds. Of much lesser effect were pavement roughness, sight distance, and road width. However, being a free speed study, no consideration was made of the effects of vehicle interaction or speed-volume effects,

and Bennett recommended that work be done to incorporate his model into a vehicle interaction model.

Horizontal curve free speed is primarily dictated by the actual curvature, with superelevation and sideways friction coefficient at the site less crucial to driver speed selection. Bennett found that approach speed also had a significant effect on curve speeds, and this relates back to the surrounding speed environment. As a result he favoured a linear regression model for curve speed prediction that could incorporate this, rather than the traditional mechanistic model used for design speed determination (Austroads 1989). Sight distances through the curve may also have a minor effect and it is not clear whether on-site curve warning or advisory speed signage have a significant effect (Koorey *et al* 2001).

Free speeds on gradients are largely controlled by the mechanical performance parameters of each particular vehicle. Upgrade speeds are limited by the maximum power-to-weight ratio (PWR) that a vehicle can use to counteract the gravitational force (with aerodynamic and rolling resistance forces generally being of much lesser magnitude). This is generally not a significant problem for modern passenger cars until the gradient is fairly steep (>4%). Long, steep downgrades can also affect speeds of heavy vehicles in particular, which have to ensure that sufficient braking power is available to them. Bennett (1994) however identified that the vertical alignment following a downgrade can also affect driver behaviour, with drivers perhaps less likely to brake in advance of another upgrade. Because trucks have a very wide range of performances, their impact on traffic along grades can vary enormously. Therefore it is important to get a very accurate representation of the heavy commercial vehicle (HCV) population when modelling.

Bennett used a form of "probabilistic limiting velocity model" (PLVM) to develop his free speed prediction model. This system, used as the basis of the World Bank's Highway Development & Management (HDM) Model (Kerali 2000), involves determining a vehicle's constrained speed from the minimum of speeds limited individually by curvature, grades, roughness, etc. This allows a more realistic interaction between the various factors that can influence driver speed selection. It is important to recognise however that this approach is only relevant for "free" speeds; traffic interaction is not accounted for.

2.2.2 Vehicle Bunching and Overtaking

Rural modelling is often used to predict changes in traffic congestion, in terms of undesired following and delays. Koorey *et al* (1999) and Koorey & Gu (2001) investigated how passing opportunities in New Zealand, such as passing lanes and slow vehicle bays, can provide both efficiency and safety benefits. Overseas theory on traffic bunching build-up and dispersion was used to develop simplified methods for determining the effectiveness of a passing facility. Key factors that affect the demand for passing include the volume and composition of the traffic, the proportion of highway allowing passing sight distance, and the speed distributions amongst traffic streams. Discontinuities such as major intersections and speed-limited areas can also have a major impact on traffic bunching.

Passing facilities can help to break up platoons¹ and reduce instances of following behind slower vehicles. Generally the "effective length" of such a facility, i.e. the length over which it improves traffic flow, extends some distance downstream of the facility itself, sometimes over 10 km further. This length is also dictated by the previously mentioned factors of traffic, sight distance, and speeds, as they determine the likelihood of faster vehicles catching up with slower vehicles again.

McLean (1989) provides a very comprehensive summary of research and methods used for analysing traffic operations on two-lane highways. In terms of overtaking, a key factor is the identification of typical gaps accepted in the opposing traffic stream or clear sight distances accepted. This will vary depending on the accelerative performance of each vehicle, the length of the vehicle to be overtaken, the surrounding road environment (including road width), and whether the vehicle is already travelling at a higher speed than the overtaken vehicle (a "flying" acceleration). Even after accounting for these, a wide variation of accepted gaps exists among drivers and a log-normal distribution is often used to represent the probability of drivers accepting particular gaps. This driver mix may also vary for different roads, with older drivers and tourists, for example, often being less aggressive.

A concept difficult to reconcile when observing vehicles in the field is that of "happy following", i.e. drivers who do not wish to overtake vehicles travelling only slightly slower than their desired speed. Most models examined tend to allow for this behaviour, but it does have to be factored in when relating bunching levels in the field to theoretical models of passing demand.

2.2.3 Roadside Development and Speed Limits

Although this project is primarily concerned with rural highway environments, many such routes in New Zealand also have a number of smaller urban localities (sometimes called "semi-rural") and other roadside developments such as "lifestyle blocks", produce stalls and tourist attractions. Often it is not practical to model around these, so they need to be incorporated somehow into any assessment of rural routes. This is particularly important when proposals involve further development of a rural area and the relevant road controlling authority wants to determine the likely operational effects on an adjacent arterial route.

Many small towns have speed limits below 100 km/h, ranging between 50 and 80 km/h depending on the location. Although driver speeds are generally affected by these limits, they are more likely to be dictated by the drivers' perception of the level of development and constriction. It is not entirely clear how much influence a posted speed sign has on the desired speeds. Most studies have focused on changes to the open road speed rather than site-specific local changes (Barnes & Edgar 1987, NHTSA 1989). While this is important should further changes in open road speed policy be considered here, it is not an effect likely to be of significance for typical project evaluations.

Osmers & Facey (2000) reviewed the changes to various speed limits in and around Christchurch, NZ, and found that mean speeds did not significantly change where

¹ Platoon: a moving group of queued vehicles led by a slower vehicle, also known as a "bunch".

speed limits were increased (e.g. from 50 to 60 km/h) and that they fell ~1-2 km/h per 10 km/h reduction in posted speed. However mean speeds at control sites fell ~1-2 km/h over the same period, suggesting that speed limit increases counteracted this local trend. It is not entirely clear why the control sites had reduced mean speeds (e.g. the stated level of enforcement did not change), although the better consistency of speed limits may have improved driver behaviour in general. 85th percentile speeds followed similar trends, and standard deviations of speed distributions generally reduced. McLean (1989) reported similar findings, with speed limits having a greater effect on high percentile speeds and hence reducing the coefficient of variation.

Away from speed-restricted areas, other developments may also have a limiting effect on vehicle speeds. This may be a function of the density of accesses in the area, the scale of the development visually, or perhaps the level of vehicles parked alongside the road. Although some effects on speeds by these factors have been found in studies (e.g. Fildes & Lee 1993), the unique nature of some developments may mean that only on-site surveys can identify the true effect on vehicle speeds.

2.2.4 Road Width Effects

Narrow road widths have potentially two important effects in terms of traffic operations on rural roads. Firstly, they may cause a reduction in mean speeds and subsequent travel time losses (slightly balanced by reduced vehicle operating costs). Secondly, they may produce a reduction in the likelihood of overtaking, especially overtaking large wide vehicles, again with travel time losses. It is important that the modelling process captures these effects.

There is no clear consensus from past research on the effects of road widths on these outcomes. Bennett (1994) summarised ten studies that suggested increases in car speeds of between 0.7-8.1 km/h (average increase 4.7 km/h) per metre of sealed road. However, whereas some researchers applied a width effect across a wide range of road widths, many only found a pronounced effect on very narrow pavements (e.g. <5m). Other researchers have not been able to find a significant width effect at all.

Standard capacity/speed analysis methods such as the US Highway Capacity Manual (TRB 2000) impose substantial penalties on roads with less than the "ideal" 3.7 m lanes and 1.8 m shoulders. However McLean (1989) found no empirical evidence for these reductions, particularly for minor reductions (e.g. 3.4 m lanes). Based on a review of available literature, he suggested that only when lane widths fell below ~3m is it reasonable to suppose that opposing vehicle interference begins to affect free speeds.

Troutbeck (1984) collected overtaking rate data on two similar highways of 7.4 m and 6.0 m widths respectively. He found that the narrower road produced slightly longer mean overtaking times and a much-reduced acceptance of smaller (<20 s) overtaking gaps. Questions remain however whether these differences are entirely due to the road width or also reflect the different functions of each road.

Data collected for the most recent update of the US rural simulation package TWOPAS showed that narrow shoulders reduce the speed of vehicles on two-lane rural highways (Leiman *et al* 1998). The findings suggest adjusting desired speeds

accordingly, with up to 6.7 km/h reduction for negligible shoulders compared with 1.8m shoulders. However the data collected on narrow lanes did not show consistent results, and so no conclusion was reached.

A key problem stated in the reviewed research has been in trying to compare "apples with apples". Surveying different width roads introduces additional effects such as local alignment, speed environment and traffic composition. For example, a wider road probably has a better likelihood of also being designed and maintained to a better standard. A more ideal research approach would be to survey some locations before and after seal widening.

Compared with the effects of other features, such as horizontal alignment and vertical grade, road width certainly does not appear to have as much influence on vehicle operations. On very narrow roads, however, the influence is much greater. For example most State Highways, with 3.5m lanes, would probably not be greatly affected, even with no shoulder present. It is important to remember however that the effect on wider trucks will be different from that on typical passenger cars. Isolated constraints such as narrow bridges may also inhibit overtaking or speeding.

2.2.5 Side Road Interaction

In many locations around New Zealand, side roads present an additional challenge for rural highway users. Conflicts may occur between through traffic and vehicles trying to enter or leave the side roads. These can cause both delays and safety problems. An adequate model needs to identify the expected effects of these on traffic operation.

Previous work has tried to relate observed traffic flows, speed distributions, manoeuvre times and accepted gaps in traffic with predicted traffic conflicts. This can then be used as a proxy for estimating the likelihood and severity of crashes at different sites. McDowell *et al* (1983) developed a simulation model to take the above field data and estimate various conflict types, and found a good correlation between these and the true crash histories at ten urban sites.

Data on gap acceptance is an important element of modelling rural side roads. Parsonson *et al* (1996) studied New Zealand drivers approaching rural intersections and found that drivers tended to judge safe gaps according to distance rather than by time, with fairly consistent minimum gaps of 150-200 m. As a consequence, they allowed shorter time gaps for vehicles approaching at higher speeds, a finding with important safety implications.

2.2.6 Safety Effects

One of the problems with most simulation models developed to date is that they have been designed specifically for evaluation of *efficiency* issues, e.g. travel time savings and reductions in time spent following. Project evaluation of rural improvements in New Zealand invariably also requires an assessment of *safety* benefits, which currently has to be done separately from the above analysis. It would be preferable to incorporate both safety and efficiency analyses into the same process for testing and evaluating proposed roading improvements.

How simulation models might assess safety is unclear. Most existing crash analysis procedures are "static" models, i.e. they simply predict crash numbers by combining typical crash rates for a certain facility, traffic volumes, and maybe additional site-specific modifying factors. In theory, using micro-simulation to model driver/vehicle behaviour, situations that put road users at more risk than others could be identified. There are however a number of methodological issues associated with this concept, which are discussed in more detail in Section 4 (Task 3).

Simulation models are generally best at predicting vehicle speeds, so evaluating safety issues related to speed seems a promising approach, e.g. the consistency of vehicle speed profiles in relation to the surrounding speed environments. A typical problem is a low-speed curve out of character with the surrounding high-speed alignment. This has been shown to have significant effects on the overall safety of a rural route (Koorey & Tate 1997). Currently research in the US is developing an Interactive Highway Safety Design Model (IHSDM) that will, among other things, address consistency of vehicle speeds along a route (FHWA 2001). This is also investigated further in Section 4 (Task 3).

2.2.7 Other Issues

Rural highways may also be subject to isolated constraints on capacity, for example one-lane bridges and roadworks with traffic control. It should be feasible to model these effects with reasonable accuracy. For example, Saunders (1988) used a SIMSCRIPT simulation to produce delay tables for one-lane bridges of varying lengths, traffic volumes, and cruise speeds.

Tate & Major (1993) derived similar theoretical measures to replicate observed delays during resealing operations. They identified effects due to temporary speed limits, the nature of the road surfacing, adjacent roadwork activity, and enforcement. Delays due to traffic control (such as STOP-GO controllers) could be modelled in a similar way to intersections, with queuing and capacity measures able to be derived.

There is some evidence that New Zealand drivers are more aggressive in some aspects than overseas drivers (Hughes 1998, Dunn & Tan 1992). This will need to be taken into account when calibrating driver performance parameters of overseas simulation models.

Another useful output of modelling is an accurate assessment of vehicle running costs. Fuel consumption models are available in some complexity these days (e.g. Biggs 1988), so incorporation of this facility is becoming more commonplace.

In summary, previous research in New Zealand and overseas has tended to focus on small elements of the overall rural roading picture. There is a need to consider the overall impacts of changes to road alignments and cross-sections for both safety and efficiency in a unified manner.

2.3 Potential Modelling Packages Available

A literature search was made of potentially suitable simulation modelling packages. One recent useful source of relevant information was the SMARTTEST project in Europe (ITS Leeds, 2000), the objective of which was to review existing micro-simulation models and identify gaps in situations modelled. The project however was very much focused on urban and freeway applications and interestingly did not identify two-lane rural simulation as a significant gap.

Based on the findings of the literature review we identified the following models as being worthy of comparison for evaluating rural highways in terms of efficiency and safety:

- TRARR 4 software (ARRB Transport Research Ltd, Australia)
- TWOPAS 98 software (FHWA, US)
- PARAMICS 2001 software (SIAS Ltd, Scotland)

As well as a general assessment of each model, field data would also be collected for calibrating and validating the models against real-life situations. Simplified theoretical models (either existing or to be developed, perhaps using generic simulation software, e.g. Simulink, SimScript) would also be considered as alternatives where feasible.

The three specified software packages were selected due to a combination of appropriateness and availability. Their attributes are discussed in more detail below. A number of similar models were also identified and are discussed in Section 2.3.4. However, difficulties in obtaining access to these models, coupled with the limited resources of this project, precluded further investigation for now. We suggest that some of these be revisited in more detail at a later stage.

2.3.1 TRARR

At present, most detailed rural simulation in New Zealand is carried out using ARRB Transport Research's TRARR software (Shepherd 1994), a microscopic simulation package. TRARR ("**T**RAFFIC ON **R**URAL **R**oads") was originally developed in the late 1970s and 1980s by the Australian Road Research Board. Originally run on mainframe computer systems, the program was ported to a PC version (3.0) in 1986. The most recent version (4.0) was produced in 1994 and included a (DOS) graphical interface (albeit with reduced functionality) and the ability to import road geometry data for the creation of road sections.

The latter greatly simplified the data creation requirements, particularly as New Zealand State Highways had been surveyed using ARRB's Road Geometry Data Acquisition System (RGDAS) in 1992. More recent road geometry data however is not in this format and needs to be converted first. Interestingly, the 10 m-interval geometry data is transformed into far coarser 100 m increments within TRARR. Figure 2.2 shows a screenshot from the latest version of TRARR.

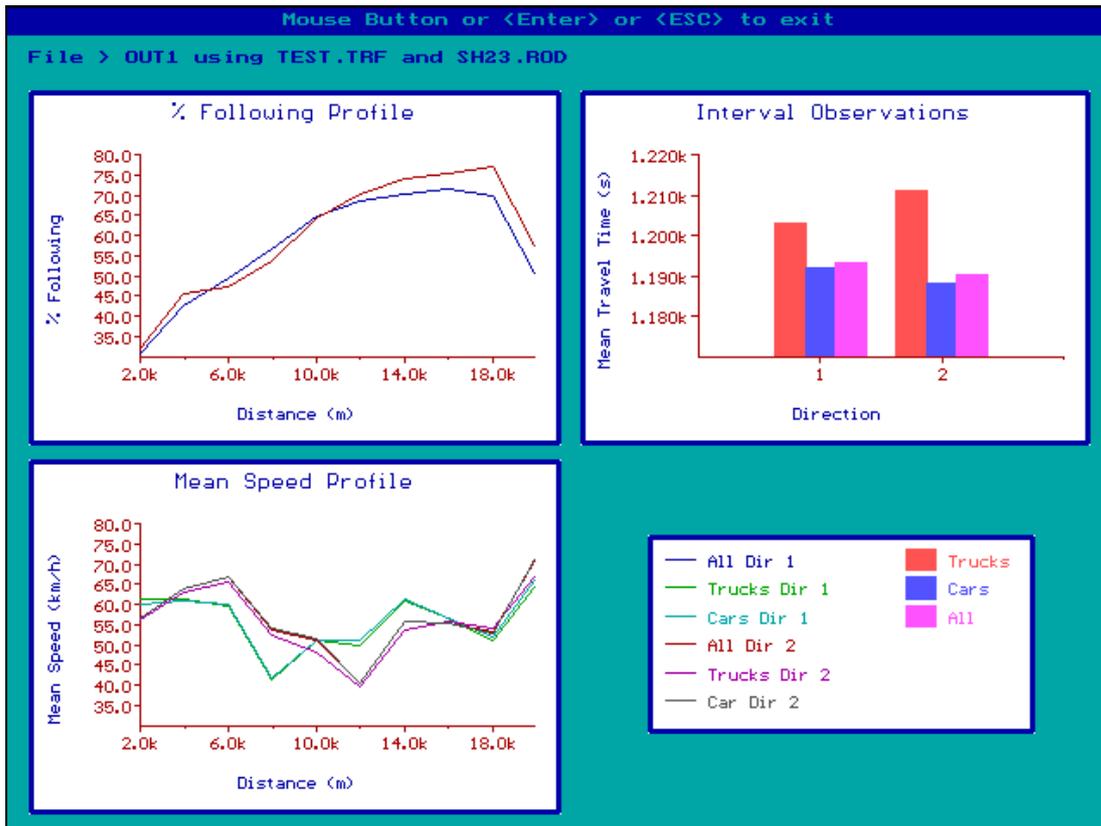
Figure 2.2 Screenshot of TRARR 4 road editor



TRARR is a micro-simulation model; i.e. it models each vehicle individually. Each vehicle is randomly generated, placed at one end of the road and monitored as it travels to the other end. Various driver behaviour and vehicle performance factors determine how the vehicle reacts to changes in alignment and other traffic. Because of this, it is important that these factors are appropriately set.

TRARR uses traffic flow, vehicle performance, and highway alignment/terrain data to establish, in detail, the speeds of vehicles along rural roads. This establishes the driver demand for passing and determines whether or not passing manoeuvres may be executed. The main outputs, mean travel times and journey speeds, are used to calculate the benefits of various project options. Figure 2.3 shows some plots derived from TRARR outputs.

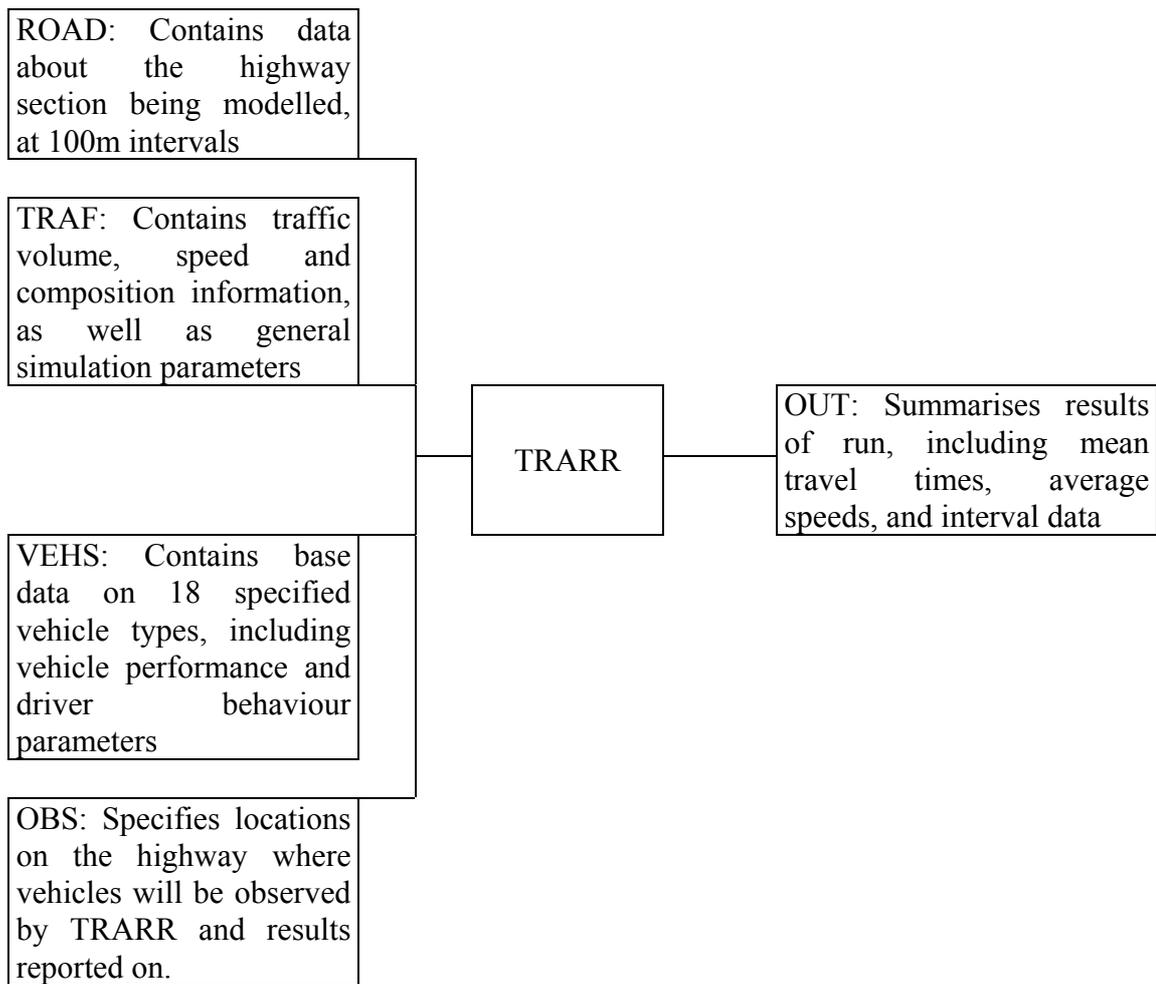
Figure 2.3 Screenshot of TRARR 4 Outputs



TRARR is designed for two-lane rural highways, with occasional passing lane or four lane sections (slow vehicle bays can also be modelled). As a result, it is ideal for modelling most of New Zealand’s rural State Highway network. TRARR can be used to obtain a more precise calculation of travel time, frustration (via time spent following), and VOC benefits resulting from passing lanes or road realignments. For strategic assessment of road links, TRARR can also be used to evaluate the relative benefits of passing lanes at various spacings.

The basic structure of TRARR’s input and output has remained largely unchanged throughout the various versions. Figure 2.4 outlines the main data files involved.

Figure 2.4 Data Files used in TRARR



TRARR is largely based on deterministic modelling, i.e. it uses fixed parameters for various inputs (e.g. vehicle power, overtaking behaviours, etc). Desired speeds for each vehicle however are randomly generated using a specified distribution (usually a normal distribution). More use of probabilistic or stochastic modelling (whereby parameters can take on a number of random values within a distribution) may improve the reality of the outputs, although it is not clear whether this additional complexity would produce significant benefits.

As a modelling tool for evaluation of rural passing lanes and realignments, TRARR has proved to be an adequate package. In particular, the ability to import RGDAS (road geometry) data from our State Highway network has been particularly effective. However a number of potential drawbacks have been identified through practical experience, limiting TRARR's use for rural simulation work in New Zealand. Koorey & Gu (2001) identified a number of concerns with TRARR. More detail is provided in their report but, in summary, these included:

- Inability to handle varying traffic flows down the highway, particularly due to major side roads; and the effect of side road interaction on main road delays.
- Inability to properly model the effects of restricted speed zones (such as small towns), roadside development or narrow road widths, without artificially adjusting TRARR's speed parameters.

- Ineffectiveness in modelling congested situations such as passing lane merges in peak holiday flows, and delays at temporary lane closures or single-lane bridges.
- Difficulty in using field data for calibration, with little guidance available and no automatic calibration assistance built into the program.
- Difficulties creating and editing road data, particularly for planned new alignments and in using recent State Highway RAMM² road geometry data, and in relating files to SH route positions.
- Limited ability to use the same tool to check for speed environment consistency and safety risks associated with various alignments (i.e. models traffic "efficiency" only).
- Additional effort required in applying speed, bunching and travel time results to Transfund project evaluations.
- Lack of practical documentation for running typical TRARR applications in New Zealand, including information on suitable field data, model calibration, appropriate parameters, and how to apply the results to derive project benefits.
- Lack of a modern interface (being a DOS-based program), with features and DOS command issues unfamiliar to many Windows-trained users.

ARRB have stated that they are not planning further development of TRARR, therefore the desired improvements will not be seen in future upgrades. What has perpetuated the use of TRARR to date has been the lack of feasible alternatives in New Zealand. There is thus an incentive to identify or develop an alternative rural simulation tool for use in New Zealand with the desired improvements.

For this project, the researcher had TRARR-4 available, as well as manuals from this and earlier versions, and in-house documentation and software tools developed to assist Opus users of the package (Koorey 2000). This software has been widely used in the past for highway design projects and strategic research, so the author is very familiar with it.

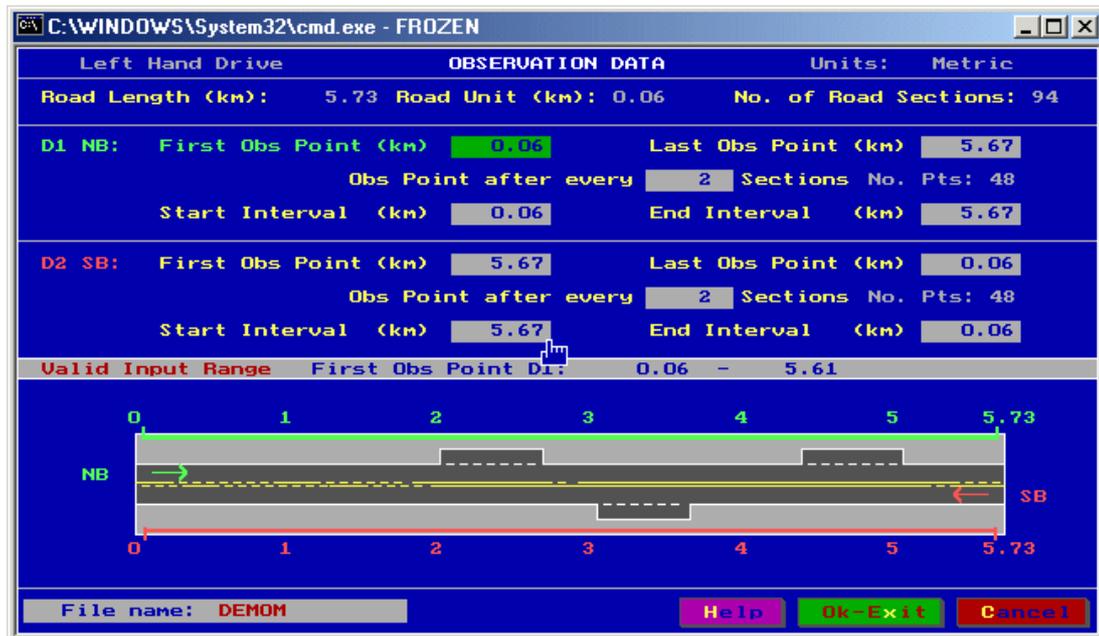
2.3.2 TWOPAS

The US software package TWOPAS (St John & Harwood 1986) is an alternative tool that appears very much worth investigating. Like TRARR, TWOPAS ("**TWO**-lane **PASS**ing") is a microscopic simulation model of traffic on two-lane rural highways first developed in the mid-1970s by MidWest Research Institute and others (St John & Kobett 1978) for the Federal Highways Administration (FHWA). The operational analysis procedures for two-lane highways in the 1985 Highway Capacity Manual (HCM) are based on an early version of the TWOPAS model.

TWOPAS was revised most recently in 1998 (Leiman *et al* 1998) to serve as the basis for updating the HCM analysis procedures in the 2000 version of the manual (TRB 2000). This work included a (DOS-based) graphical interface UCBRURAL, developed by the University of Berkeley, California. Figure 2.5 shows a typical screen (selection of observation points) when running the "front-end" interface.

² RAMM: Road Asset Maintenance and Management system: road inventory database maintained by Transit New Zealand.

Figure 2.5 Screenshot from TWOPAS Front-End (UCBRURAL)



TWOPAS simulates the operation of each individual vehicle on the roadway. The operation of each vehicle as it advances along the road is influenced by the characteristics of the vehicle and its driver, by the geometrics of the roadway, and by the surrounding traffic situation. The simulation contains a comprehensive overtaking sub-model allowing for both sight distance and opposing-vehicle-restricted opportunities, and for single and multiple overtakings. The following features are found in TWOPAS:

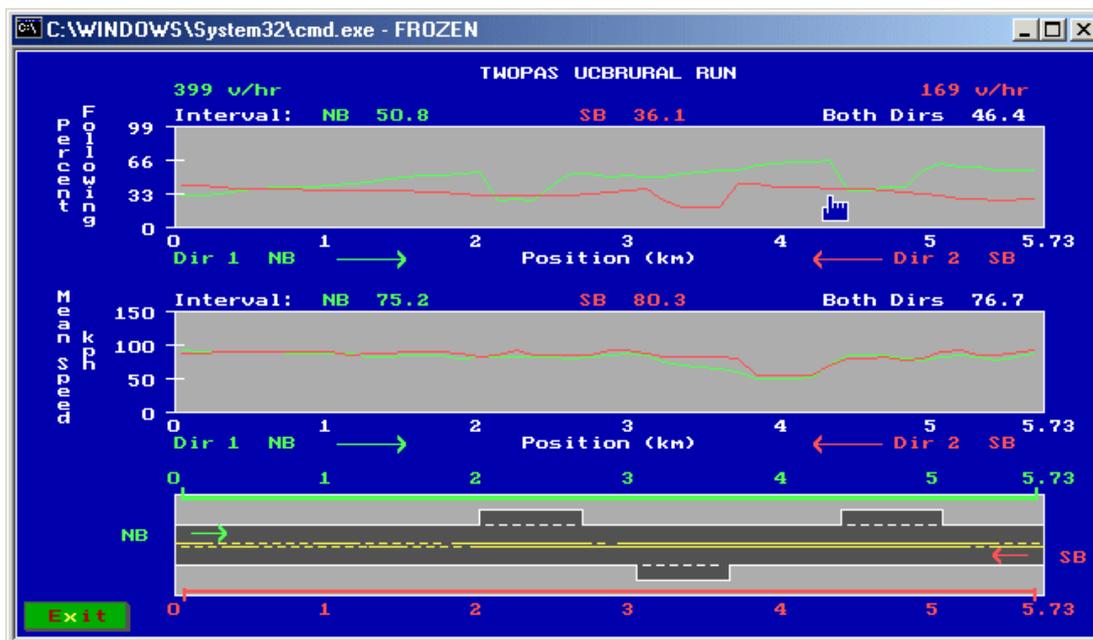
- Three general vehicle categories - passenger cars, recreational vehicles, and trucks, placed in 13 sub-types.
- Roadway geometrics are specified by the user as elements in input data, including horizontal curves, grades, vertical curves, and auxiliary lanes.
- Traffic controls are specified by the user, particularly passing and no-passing zones marked on the roadway.
- Traffic streams enter at each end of the simulated roadway generated in response to user-specified flow rate, traffic mix, and percentage of traffic platooned.
- Variations in driver performance and preferences are based on field data.
- Driver speed choices in unimpeded traffic are based on user-specified distribution of driver desired speeds.
- Driver speed choices in impeded traffic are based on a car-following model that simulates driver preferences for following distances (headways), based on relative leader/follower speeds, driver desired speeds, and desire to pass the leader.
- Driver decisions concerning initiating passing manoeuvres in the opposing lane, continuing/aborting passing manoeuvres, and returning to the normal lane, are based on field data.

- Driver decision concerning behaviour in passing/climbing/four-lane sections, including lane choice at the beginning of an added lane, lane changing/passing within added lanes and at lane drops, are based on field data.
- Processing of traffic and updating of vehicle speeds, accelerations, and position is done at intervals of one second of simulated time.

TWOPAS has been updated to incorporate changes in driver and vehicle characteristics and to allow users to adjust for the effect on traffic operations of narrow lanes or shoulders and limited speed zones. Another major enhancement in the latest version is the capability to automatically generate available sight distance based on user specified offsets to sight obstructions.

TWOPAS uses just one input file to specify road and traffic parameters, and another file to hold default values such as vehicle performances. The simulation produces a very detailed output file, although an accompanying program, TWOSUM, is also available to produce more succinct and useable summary reports. The results can then be viewed within UCBRURAL; Figure 2.6 shows an example of this. Although all of these files are text files, the standard TWOPAS input file has few prompts to describe the data contained, making it difficult to edit manually without additional documentation.

Figure 2.6 Typical outputs from TWOPAS



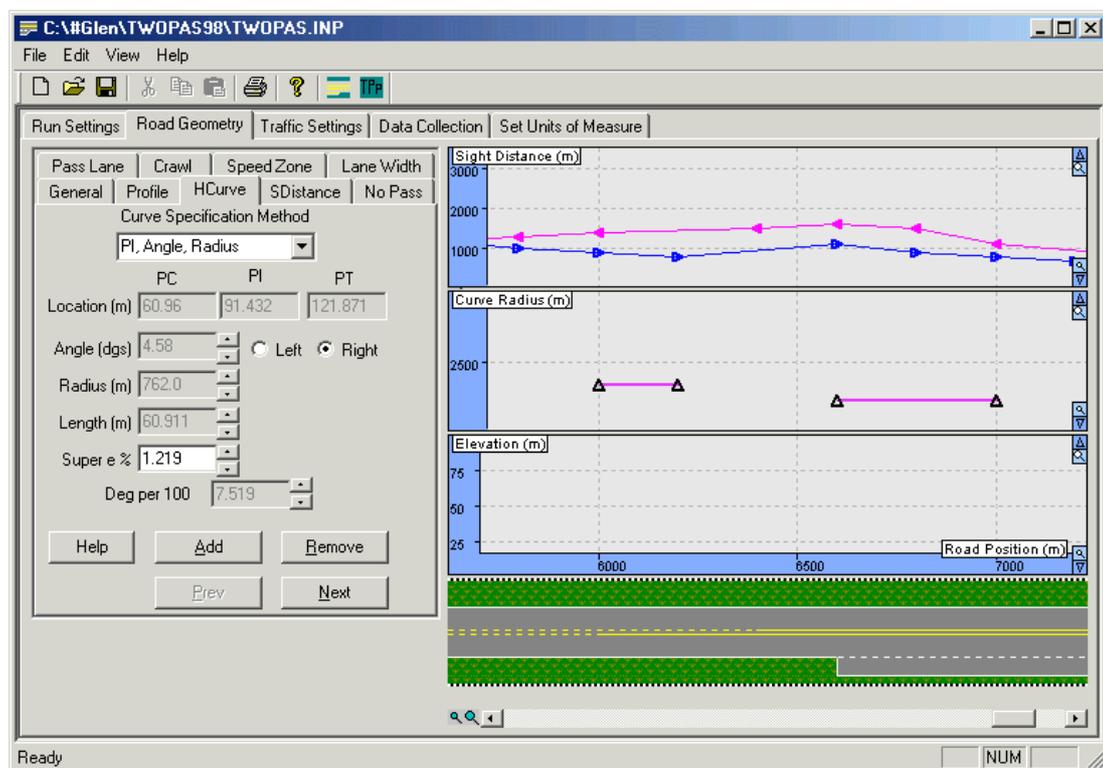
In the past some comparisons of the capabilities and features of the TRARR and TWOPAS models have been undertaken with mixed results (Botha *et al* 1993, Staba *et al* 1991). It was found that their capabilities and features are comparable in many respects, with preference often based on local needs. For example, those with geometry data available in terms of elements found TWOPAS far more practical for their needs. Conversely, some found TRARR's simpler outputs to be more useable than TWOPAS's rather extensive results. It is significant however that, with suitably calibrated models, both models were found to give sufficiently adequate results. In the past, preference has tended to be based on local familiarity, with TWOPAS preferred in North America and TRARR preferred in Australasia.

While TWOPAS appears to be a promising alternative to TRARR, work is needed to confirm its validity and practicality for use here. Some issues, like its lack of direct compatibility with RGDAS road geometry data, need to be considered and solutions identified. Although the UCBRURAL front-end enables data entry in metric units, the underlying program still uses Imperial units, which could also cause problems if dealing with TWOPAS directly.

For this project, the researcher had a copy of TWOPAS-98 available for evaluation. Unfortunately the original manuals (St John & Harwood 1986), which contain much detail of the underlying model parameters, have proved difficult to obtain, leaving only the basic documentation provided with this version. Some correspondence with the US developers has also been undertaken.

Some further work is now continuing to improve TWOPAS even further, as part of the FHWA Interactive Highway Safety Design Model (IHSDM) programme (FHWA 2001). Improvements planned include allowance for vehicles turning on or off side roads, and a Windows interface. This ongoing development of TWOPAS makes it an attractive proposition to consider when compared with TRARR. An updated Windows version of TWOPAS became available for testing in late 2002 (after the completion of this study) and Figure 2.7 shows a screenshot from an earlier beta version obtained. At the time of review, the newer version did not appear to be sufficiently stable to test fully, nor did it add significant functionality to earlier versions. Therefore the earlier TWOPAS-98 has been used for evaluation in this project.

Figure 2.7 Screenshot of beta TWOPAS Windows version

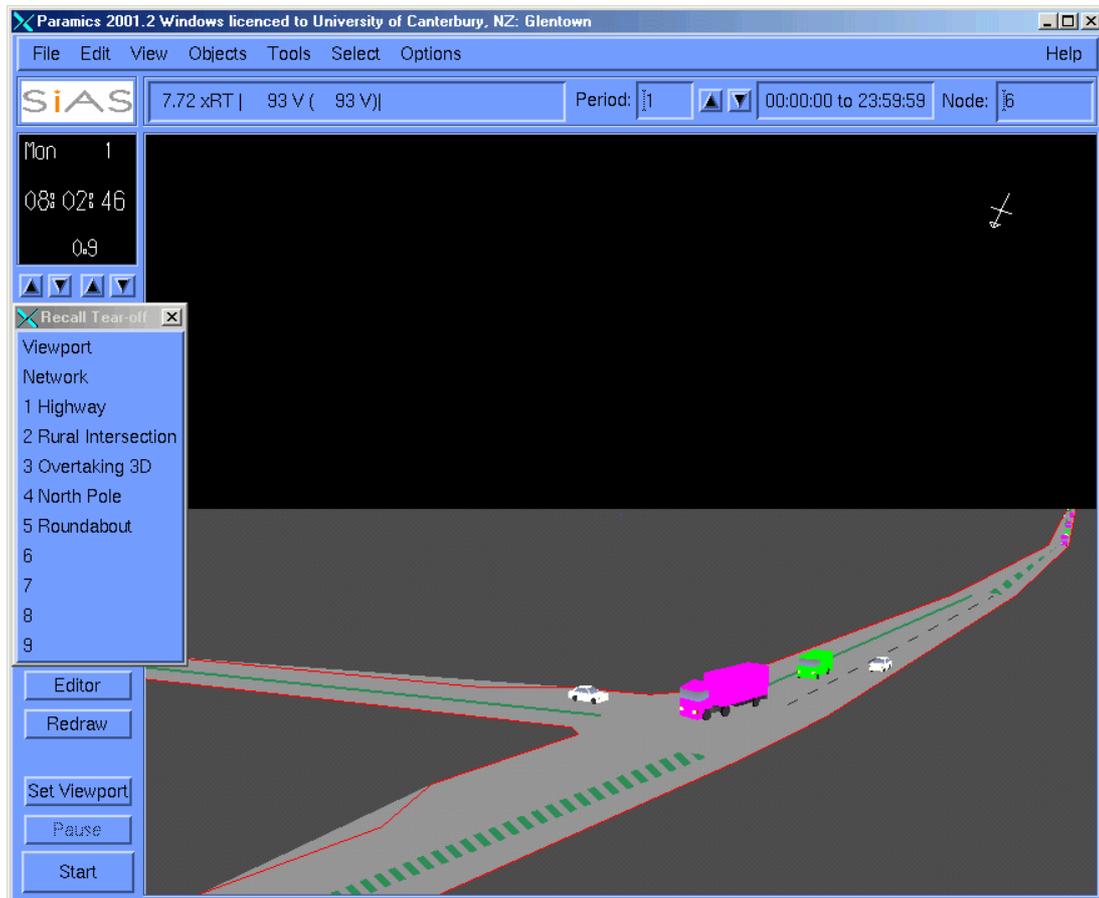


2.3.3 PARAMICS

Much of the development of traffic models in recent times has focused on (often complex) urban and motorway networks. In the past, computing power has limited the ability to model these networks in great detail, resulting in "macro-simulation" packages that rely largely on speed-flow curves to determine link flows and efficiencies, e.g. SATURN by WS Atkins (UK). Now a number of software tools have been developed to take advantage of micro-simulation techniques and one such tool is PARAMICS, produced by SIAS Ltd (Scotland).

PARAMICS simulates the individual components of traffic flow and congestion, and presents its output as a real-time visual display for traffic management and road network design. PARAMICS micro-simulation is concerned with modelling individual vehicles for the duration of their journey through a network, with the route that a driver chooses not being predetermined, but depending on the network situation being encountered. The conditions in the model vary with time and drivers adapt their behaviour (e.g. route choice) in response to this. Thus a PARAMICS model is not a traditional network equilibrium model, but a dynamic model.

PARAMICS has been developed over more than ten years by UK traffic and transportation engineers. The name PARAMICS ("**PAR**allel **MI**Cro**S**imulation") is a legacy of its initial focus on running complex simulations on parallel processors. Earlier versions were only available for Unix systems, such as Linux PCs and Solaris servers, but a Windows PC version (running on a Unix X-Windows emulation) has been available for the last couple of years. PARAMICS 2001 Release 2 is the latest version, and improves on the editing abilities to simplify data entry (SIAS, 2001). Figure 2.8 shows an example of 3D visual modelling within PARAMICS (models can also be viewed in 2D or batch-run without visualisation).

Figure 2.8 3D Screenshot from PARAMICS

Three interacting models applied at the same time govern the movement of individual vehicles in a PARAMICS model; car following, gap acceptance and lane changing. In addition, drivers have certain behavioural characteristics randomly assigned to them – aggression and awareness. These factors represent the characteristics of drivers that result in their different performances with regard to gap acceptance, car following and lane changing. Top speed, headway and lane usage are also influenced by these factors. Some simple vehicle dynamics are also taken into account, such as size, weight (e.g. for tonnage restrictions), acceleration and deceleration.

The road network is coded into the software in considerable detail and the success of the modelling depends somewhat on the accuracy of the road layout description. Unlike macroscopic network models, neither travel times nor intersection capacities are entered into the model. The input data includes details of nodes, links and a large number of other details describing the network, such as number of lanes, parking or bus lanes, bus stop positions, traffic signal data, movement definitions and priorities at intersections etc. An important factor is how well the network is segmented into links, as PARAMICS "looks ahead" only two links when determining the next action of each vehicle.

One of the strengths of this micro-simulation is that it can show an easily understood graphical display of real time traffic flow on a computer screen. Although measurement and validation of network statistics will still be required to confirm the

model's accuracy, major problems can be quickly identified using the maxim "if it looks wrong, it probably is wrong". This approach should help to minimise "coding errors", as opposed to the traditional analysis by abstract accumulation of numerical data and related plots. The visual display also enhances the perceived validity of such models with both transport professionals and lay people alike.

Although primarily aimed at urban networks and inter-urban motorways (where congestion effects tend to dictate vehicle speeds), it appears possible to apply PARAMICS or a similar model to a typical New Zealand rural highway, where geometric constraints may dictate. Some gradient and curve information can be entered and additional lanes and speed limits can also be specified. Laird and Nicholson (2000) developed the first urban PARAMICS model for New Zealand and were able to show that this micro-simulation software can be used to simulate New Zealand urban road conditions and driver behaviour accurately. Given the increasing use of these models in New Zealand for other applications, the relative merits of also applying them to rural highways are worth exploring.

A key difference from modelling many urban networks is that rural studies are generally linear in nature, e.g. along a State Highway. This limits the application of the route choice component of PARAMICS to network reliability studies and the like. However, the ability to add side roads along the route and additional traffic at small towns provides a useful addition to the existing rural modelling capability.

For this project, the author was based at Canterbury University, which currently holds appropriate licences for the PARAMICS 2001 package (Release 2), as well as all relevant documentation. The author has also maintained contact with PARAMICS experts both locally and at SIAS.

2.3.4 Other Simulation Models

Both TRARR and TWOPAS are specifically designed for modelling rural highway links, and there is little else in the world currently developed for this application. HUTSIM from Finland's VTT is one other recent example, but the author has been unable to obtain sufficient information on this package; it also appears that the latest focus has been on urban modelling.

Another well-established rural simulation model is the Swedish National Road and Traffic Research Institute (VTI) program (McLean 1989). Originally developed in the mid-1970's, VTI is actually part of a suite of programs for modelling traffic effects of roads. As with the other models described above, VTI takes road geometry and vehicle performance inputs to predict overtaking, vehicle speeds and so on. The Centre for Traffic Simulation Research (CTR) has recently been granted funding to modernize the VTI model, rewriting the old SIMULA code in Borland Delphi for Microsoft Windows with animation (Andréasson 2001). At the same time it will be integrated with a model for movements (trajectories and gap acceptance) in non-signalised intersections. The existing VTI model has been used to assess safety with respect to decisions to overtake with insufficient sight distance and to assess the effects of cruise control on overtaking. The updated VTI model may be worth investigating in New Zealand, but the timing of this research precludes it for now.

A parallel development in rural highway modelling has been the World Bank's Highway Development & Management (HDM) research (Kerali 2000). This model has been used for over two decades in many countries to combine technical and economic appraisals of road projects, to prepare road investment programmes and to analyse road network strategies. Although primarily concerned with optimisation of road maintenance investment, HDM also allows the analyst to consider the expected benefits of new construction, e.g. realignments, bypasses or road widening.

Following an intensive research programme to improve the underlying technical relationships, the most recent version (HDM-4) was released in 2000. Amongst its improvements were additional capabilities for modelling traffic congestion, safety, road works and environmental effects. An extensive range of motorised and non-motorised vehicles can be used, with a detailed speed prediction model to determine travel time and vehicle operating costs. Note that HDM-4 is not a micro-simulation tool; it merely models effects over the long term by calculating road user costs year by year.

While in theory the HDM-4 model can be used to assess the merits of a new roading improvement, in practice it is more suited to strategic-level analysis. Typical HDM road network data is usually very coarse in nature and only records aggregate information on geometric attributes for each section. For safety analysis, the crash rate models currently incorporated are very primitive, similar to the simple terrain-based crash rates used in Transfund New Zealand's *Project Evaluation Manual* (Transfund 2001). While both of these issues can be addressed by providing project-specific data, the end result is still likely to be rather simplistic. For example, the effect of a passing lane on congestion would be determined by simple speed-volume relationships and these are normally calibrated locally anyway.

Apart from PARAMICS, a number of similar network micro-simulation packages have also been developed in recent years, such as AIMSUN (TSS, Spain), VISSIM (PTV, Germany), and DRACULA (ITS Leeds and WS Atkins, UK). AIMSUN has been used by Transit New Zealand for modelling the Auckland Motorway network (Hughes 1998). These packages could possibly also be tested in the future for their applicability to rural modelling, subject to their availability in New Zealand.

It may be that the level of detail involved in the above simulation models provides little additional information than what could be provided from a simpler form of model (although given the work that has gone into simulation models, that is unlikely). Generic simulation packages, such as SimScript and GPSS/H for example, could be used to develop a simplified vehicle interaction model that provides a sufficiently adequate level of accuracy. Alternatively, an even simpler calculation approach may be appropriate, such as the recent improvements to two-lane highway evaluation in the US Highway Capacity Manual (TRB 2000).

Another long-term possibility is to incorporate road-modelling features into existing road design packages. Programs such as MX-ROAD by Infracore can already produce sophisticated designs for realignments. At the moment this information then has to be exported into an existing program like TRARR for evaluation of benefits. It may therefore be more practical for assessment of these designs in terms of road user

benefits and costs to also be built in, enabling more immediate feedback on the most optimal designs.

2.4 Assessment of Packages in Terms of Desired Features

It is pertinent first to consider the chosen models in terms of the framework given in Section 2.1. A cursory comparison of the models shows that all three fail to provide every one of the listed outputs, or take account of all of the listed inputs.

For example, currently TRARR can only produce outputs on vehicle speed (and hence travel times), running costs and vehicle emissions via petrol/diesel consumption, although arguably its overtaking rate outputs can also provide some guidance on safety and driver comfort issues. In terms of inputs, TRARR takes no account of driver factors (other than assuming a typical driver for each vehicle type) or road environment features, but road, traffic and vehicle data can be specified in a fairly detailed manner.

TWOPAS is very similar, with PARAMICS even less detailed when it comes to relevant inputs.

In terms of improvements needed for the models in general, road environment features are key inputs that appear to be missing in our current analyses. The driver input category is not likely to be a direct input into a practical model for users. Rather, a representative series of behaviours is likely to be inferred based on observed actions on the road.

In terms of outputs, the lack of safety performance measures is a key omission, although work in this area is now beginning to appear (as will be discussed in Section 4). Driver comfort measures are an evolving area of project evaluation that may not have sufficient research and understanding to be able to implement at this stage.

In assessing technical models, it is useful to be able to see how the underlying routines work in some detail. This helps the user have some faith in the robustness and logic of the model, rather than treating it as a "black box" for entering data and obtaining results. Where this background information is not available, then the user must resort to testing known real-life situations and seeing how well the model reproduces them. A combination of these approaches was used to assess the models available for this project.

Both TRARR and TWOPAS have relatively good detail available on the underlying program logic and algorithms used (Hoban *et al* 1991, St John & Harwood 1986). Updates to the models have also been well recorded in technical literature (e.g. Leiman *et al* 1998, McLean 1991). This is largely a function of their public domain origins, having been used extensively by the Australian and US governments for national highway research.

In contrast, probably because of its more commercial background, less is known specifically about the algorithms used in PARAMICS for car following, gap acceptance, and so forth. Although the graphical representation of the modelling

helps users to assess whether the model *seems* realistic, over a large number of vehicles it may be relatively minor differences in speed or timing that make a significant difference to the perceived effectiveness of a project. There is also a concern that PARAMICS may be less applicable to situations it was not originally conceived for, such as rural highway modelling in New Zealand (as opposed to urban and motorway networks in UK). Without more information on how it deals with various situations, this can only be tested through field studies.

The previously suggested modelling framework and discussion of key features identified a number of features of rural road sections (in terms of inputs or outputs) that would be desirable for the proposed software tools to model. These include:

- Free speed prediction, especially on grades and curves
- Vehicle interaction, bunching and overtaking
- The effects of additional lanes (e.g. passing lanes, four-laning, slow vehicle bays)
- The effects of speed limits and roadside developments
- Side road interaction with main road traffic
- The effect of constraints such as narrow roads, one-lane bridges, roadworks, etc
- Prediction of vehicle running costs
- The ability to assess conflicts between vehicles and to predict relative safety.

The practical aspects of modelling rural highways, as discussed in section 2.1.1, also need to be considered while testing the above scenarios.

Table 2.1 summarises the capabilities identified in each of the selected models, based on an initial investigation of each package. Note that this table does not give an indication of how well each model simulates these scenarios; it merely identifies those features that can be directly specified in the model or at least modelled by indirect adjustment of other parameters. Also listed are some of the underlying areas of theory commonly used to model these effects, which (as well as being used in the simulation packages) could be used to derive simplified analyses of these scenarios.

Table 2.1 Summary of Capabilities of Selected Simulation Models

Rural Modelling Task	TRARR 4	TWOPAS 98	PARAMICS 2001	Underlying Theories
Curve Speed Prediction	Yes	Yes	Unsure	Force Equilibrium, Veh Kinematics
Gradient Speed Prediction	Yes	Yes	Yes	Veh Power/Weight, Force Equilibrium
Two-Lane Bunching/Overtaking	Yes	Yes	Yes	Passing Demand & Supply, Veh Following
Passing Lane Overtaking	Yes	Yes	Yes	Expected Overtaking Rates
Four-Laning Operations	Yes	Yes	Yes	Speed-Flow Curves, Veh Following, Lane Changing
Speed Limits	Adjust speed indices	Yes	Yes	Empirical Observations
Roadside Development	Adjust speed indices	Adjust speed limits	Adjust speed limits	Empirical Observations
Road Width Effects	No	Yes	No	Empirical Observations
Side Road Traffic	No	In future version	Yes	Queuing, Gap Acceptance, Veh Kinematics
Delays at Constraints (roadworks, one-lane bridges)	No	No	Yes	Queuing, Gap Acceptance, Veh Kinematics
Estimation of Fuel Consumption	Yes	No	Yes	Veh Operating Cost Model
Assessment of Safety / Conflicts	No	Indirectly via aborted passes	Indirectly via "Events"?	Traffic conflicts, Aborted manoeuvres

The above table shows that not all capabilities are present in every model, limiting the level of comparison that can be made between packages. On the surface, it appears that TWOPAS has benefited from more recent upgrading, in having a few more capabilities than its TRARR counterpart; however the robustness and practicality of these features remains to be tested. PARAMICS shows advantages in areas of non-linear vehicle interaction, a legacy of its network-modelling heritage, but its ability to accurately model the effect of basic geometric attributes is unclear.

The prediction of mean desired free speed on unconstrained alignments is not included in the list of tasks. This is because it is generally an input value into each model. Of more importance is how well each model predicts speeds that are constrained by either road geometry or traffic conditions.

2.5 Comparison of Models with Field Data Survey Information

To be able to test these scenarios against actual vehicle/driver behaviour, suitable sites from around the country were identified for field data collection. In some cases, sites already had some data collected as part of other studies and this was taken into consideration when selecting sites. Sites ranged from spot locations (for speed surveys) to sections more than 5km in length (to assess changes in measures, such as speed and bunching, along the road).

To minimise survey travel costs, sites were generally based around the principal researcher's location in Christchurch (Canterbury). Potentially this could bias the results, in that models calibrated in Canterbury may not be representative of other parts of the country. Where possible, data from studies elsewhere were examined for comparison, e.g. the curve speed data around Wellington region from Koorey *et al* (2001).

Bennett (1994) noted a similar problem in that all of his survey sites were in the North Island. At the time, South Island mean free speeds were about 3-5 km/h lower than the North Island, possibly explained by differences in traffic stream compositions. In annual rural speed surveys over the past five years, mean speeds in Canterbury have consistently been 2-4 km/h above the national average, with 85th percentile speeds 1-3 km/h above the average (LTSA 2001a). However on State Highways, the Canterbury region has generally mirrored the national average since 1993 (LTSA 2001b).

As far as possible sites were selected so that one particular attribute could be examined in isolation of others. For example, a curve site should not have additional influences of gradients, speed limits, narrow lanes, side roads or passing lanes. By attempting to control for these other factors, the effects of each can be identified both in the field and in the corresponding models.

Ideally, where a road upgrade is about to be constructed, site data could be collected before and after construction, to first calibrate and then validate the models. However the time frame for this research, and the available road projects, precluded that. An alternative considered, but not taken further, was to use previously collected data from a past project to enable comparison with the newly constructed alignment.

Field data is often used to calibrate a particular model. However, it is desirable to see how well the chosen models perform without too much site-specific calibration. In breaking down the surveys to focus on specific issues (e.g. curve speeds, gradients, passing, etc) the aim was to see how robust the models appear in each case with only limited calibration of factors such as desired free speeds and vehicle types/parameters/proportions. If a model is not performing correctly after doing that then other traffic parameters can be adjusted to make it fit (e.g. initial bunching proportions), but this limits its general applicability. A more critical factor, however, may be how well the road conditions can be replicated in each model, especially given the relative coarseness of road section lengths that may have to be applied.

Having calibrated a model, separate field data is often used to validate its correctness for other locations or traffic conditions. For some surveys, validation data was available by recording separate survey periods with different traffic flows. In other cases, additional survey sites had to be obtained. Alternatively, having calibrated individual model features using various individual surveys, it might be worthwhile to validate them all on one separate site to see if they interact together as predicted, but this was not carried out.

To improve the fairness of comparisons, the vehicle composition and performance data was replicated as much as possible. Fortunately all three of the simulation models allowed for specification of a wide range of vehicle types and key parameters such as acceleration and weights.

The sites chosen for data collection were surveyed as required to collect adequate field data. Some examples of data collected include:

- Traffic count profiles and composition mixes (proportions of trucks, towing vehicles, etc), either by automated means or manual observation surveys.

- Typical driving speed profiles and other data along the site length, using Opus Central Laboratories' portable vehicle-mounted speed profiler.
- Spot speeds, particularly on grades and at curves, using hand-held radars or interval measurement equipment (e.g. digitectors, optical sensors developed by Central Laboratories).
- Vehicle bunching levels (i.e. proportion of vehicles following closely), either by automated means or manual observation surveys.
- Video or manual observation of driver behaviour in complex situations such as intersections or merges.

Automated data collection can still suffer from accuracy problems, especially when classifying vehicles. Where possible manual survey methods were therefore used, with automated data only used where long survey durations were required or where a large sample size was required to minimise sampling errors.

Minimum required sample sizes were identified to reduce sampling error. For practical scheduling purposes, time-based minimums (based on expected traffic flow) were generally used, subject to a reasonable sample size having been collected. Although sample sizes of 300-400 are technically required for 95% confidence intervals of ± 1 km/h, negligible increases in the accuracy of estimated mean speeds have been found from more than 80 vehicles recorded (Keall 2001). In practice, a minimum of two hours surveying has been shown to be statistically acceptable for monitoring purposes on most rural roads.

Following data collection, accurate representations of the sites were set up using each of the simulation models. As well as the field data collected, other available road inventory information was also incorporated, particularly RAMM road geometry and cross-section data.

For some surveys, it may be preferable to model the exact stream of vehicles that was observed in the field. TRARR has a facility that allows input of specific vehicles and origination times, while PARAMICS allows the specification of fixed route scheduled vehicles (commonly used for bus services). The practicality of using these facilities for model validation was investigated, but not considered further in this study.

Each model was assessed for ease of setting up the required scenario and for how well it represented the true situation as shown by the field data. From this analysis, conclusions were then drawn as to the applicability of each model for New Zealand conditions.

2.6 Development of Survey Plan

The following data collection tasks, summarised in Table 2.2, were proposed in Task 2 to enable validation of the models.

Table 2.2 Proposed Surveys for Validating Simulation Models

Rural Modelling Task	Collection Method	Details
Curve Speed Prediction	Existing curve speed data + digitector speeds	Compare previously surveyed speed data at two sites near Wellington with modelled speeds. Survey isolated and series of curves for additional data
Gradient Speed Prediction	Radar/digitector spot speeds	Manually collect speed/classification data at the start and end of known up-grades in Canterbury.
Two-Lane Bunching/Overtaking	Existing headway data, Spot bunching surveys, vehicle overtaking surveys	Compare changes in bunching over distance on flat/rolling/mountainous sites in Canterbury. Number plate surveys over same sites. Survey acceptance of sight distance & vehicle gaps for overtaking from slow moving vehicle
Passing Lane Overtaking	Number plate surveys, observation surveys	Passing lanes south of Chch, look at overtaking rates vs volume, also overtaking locations within PL
Four-Laning Operations	Automated counters	Speed-volume comparison of Chch Northern Motorway
Speed Limits	Radar/digitector spot speeds, number plate surveys	Survey mean free speeds vs posted speed, local Canterbury towns. Also survey time to traverse through town, derive average speed.
Road Width Effects	Digitector spot speeds	Collect free speeds on tangents of varying width.
Side Road Traffic	Manual Observation	Use handheld PSIONs to collect information on vehicle arrivals and departures at rural T-junction.
Delays at Constraints (roadworks, 1-lane bridge)	Manual Observation	Hurunui one-lane bridge study. Survey queues at sealing works.
Estimation of Fuel Consumption	Instrumented Vehicle	Drive from Lower Hutt via Rimutakas to Masterton (variety of terrains). Collect fuel consumption information along the way.
Assessment of Safety / Conflicts	Manual Observation	Conflict surveys at rural intersection

The proposed tasks are discussed in more detail in the following sections. Time and budget constraints precluded carrying out all of these surveys, particularly when unforeseen problems (e.g. equipment failures) occurred during their implementation. Similarly, technical difficulties with the simulation packages prevented full analysis of the results being done. However the surveys and analyses were generally programmed in order of most important to least important. Section 3.2 describes the actual surveys and data analysis undertaken in this study.

Based on this proposed survey brief, the survey programme was only able to offer a preliminary look at each of the various attributes investigated. Further work to examine some of the attributes in more detail would have required a greater selection of sites, and this should be carried out at a later date.

It should be reiterated that assessment of safety does not seem to be adequately addressed by any of these packages; therefore these surveys do not focus on this area. Instead, a review of alternative models to use for road safety is made in Section 4.

2.6.1 Curve Speed Prediction

Data collected from a previous study of curve advisory speeds (Koorey *et al* 2001) would be re-examined in this study. Speeds approaching and travelling through selected curves were collected at two sites with high and low curve speeds respectively. Other sites had only speeds within the curve collected, but may also be examined for simple validation.

Because speeds at the above sites could have been slightly affected by the presence of the advisory speed signs, further surveys would be carried out around Canterbury at selected curve sites. These would make use of either the optical speed sensors (developed by Opus Central Laboratories for the curve advisory speed research) or standard tribo-electric wires connected to a digitector to record spot speeds through the tightest part of the curve. Ideally, at least one site would be an isolated curve following a long straight, while another site would be within a series of tighter curves. Surveys would be at least two hours in duration and, to simplify analysis, sites with significant gradients were to be avoided. The Canterbury Plains provided many examples of the former, with sites in the latter category available nearer the surrounding hills.

2.6.2 Vehicle Performance and Gradient Speed Prediction

McLean (1989) outlines an experimental method to determine power/weight ratios on grades of a known length and elevation. This was used by Bennett (1994) to collect vehicle performance data for his research. The subsequent vehicle parameters can then be incorporated into simulation models for comparison of predicted speeds with observed speeds on gradients.

It was proposed to carry out similar surveys on two significant gradients in the Canterbury region. Speed and classification data would be collected for vehicles at two known points on a gradient. From the relative speed change, vehicle power/mass performance could be estimated. Sites with high-speed approaches and relatively straight gradients would be used, e.g. north of Porters Pass. Data would be collected either using radar gun or digitector, for at least two hours.

2.6.3 Two-Lane Bunching/Overtaking

Three types of survey were considered. Firstly, automated surveys of changes in vehicle bunching would be collected along routes of differing terrain (flat, rolling, mountainous). At least three locations along each route, covering approximately 5-10 km, would be surveyed simultaneously using classifier-counters and the resulting data sorted by traffic volume. The chosen routes would then be modelled by simulation to compare the predicted and observed bunching changes.

The same sections would also be surveyed using number-plate surveys at each end. From these, the number of passes could be inferred over the study length. The corresponding overtaking rates can then be compared with those predicted by the simulation models.

Additional surveys may attempt to determine accepted gaps in sight distance and oncoming vehicles that drivers would accept for overtaking. Troutbeck (1984) used a similar method and variations of the techniques are summarised by McLean (1989). The surveys would involve a slow-moving observation vehicle whose occupants record details of vehicles that catch up and overtake. This information is related to the timing of oncoming vehicles or approaching sight distance restrictions to estimate accepted overtaking gaps used by drivers. The speed profiler device, developed by Opus Central Laboratories, could be used for this work, using the function keys to record the various events noted along the way. For opposing vehicle

gaps a long straight section would be desirable for collecting data, while for sight distance restrictions, a series of curves and short straights is preferable.

2.6.4 Passing Lane and Four-Laning Operations

Number-plate surveys would be carried out at each end of a long busy passing lane just south of Christchurch for at least two hours. From these, the number of passes could be inferred over the passing lane length. The corresponding overtaking rates could then be compared with those predicted by the simulation models.

On the same site, separate observation surveys would also be carried out to identify where the overtaking is occurring within the passing lane. This data would also be compared with the simulation model predictions.

When four-laning is planned, congestion effects are often a major component of the justification for it. It is important therefore to know how the proposed four-laning will address these effects. Automated survey data previously collected from the Christchurch Northern Motorway between Kaiapoi and Belfast would be obtained to develop speed-volume relationships. These could be compared with similar relationships produced by the simulation models.

2.6.5 Speed Limits and Roadside Development

Ideally at least six approaches to small towns in the Canterbury region with speed limits would be surveyed for how the mean free speeds change on approaching the township. Sites would be selected where high approach speeds were likely (i.e. long straight) and there were no curvature constraints soon after the speed limit interface. At least eight potential sites at town entrances, with speed limits between 50-80 km/h, were identified in central Canterbury. The relative level of delineation at the speed limit interface (e.g. presence of additional "traffic calming" devices) could also be considered, as could the level of roadside development near the interface. Speeds would be collected approximately 400m before the speed limit interface, at the interface, and 400m after the interface, using a series of detectors monitored for at least two hours per site.

Number plate surveys at each end of small towns could also be used to determine the mean travel times through them. This could be compared with the times predicted by the simulation models. Similarly, bunching surveys could assess the effect of small towns on vehicle queuing.

Consideration was given to further possible surveys comparing mean speeds with other factors such as access density. However this introduces additional complexities and it was felt that for now any such sites should be specifically surveyed for mean speeds and models adjusted accordingly.

2.6.6 Road Width Effects

Surveys of mean free speeds would be carried out at four locations of varying lane width. The locations would be on fairly long unconstrained straights to obtain good estimations of maximum desired speeds. Because most simulation modelling is likely

to take place on major routes with a good standard of road width, sites selected would not be exceptionally narrow, e.g. <3m.

Standard digitector speed surveys would be used to collect the speed data, for at least three hours per site. Sites would be located where possible along the same routes or at least along similar routes in the same area. For example, SH77 between Rakaia and Darfield has lanes ranging in width from 3.1 – 3.5m, and thus could provide a suitable selection of sites.

2.6.7 Assessment of Delays and Conflicts from Side Road Traffic

Two rural T-junctions would be surveyed manually by observation to determine gaps accepted (and rejected) when turning and typical acceleration and deceleration delays. The sites would be on Canterbury highways and have good alignment, sufficient turning flows and turning lanes present. Handheld PSION Organisers would be used to record vehicles passing various points at and near the intersection, for at least three hours. The resulting intersection performances could be compared with a PARAMICS simulation of each site.

The same sites may also be surveyed for another three hours to assess traffic "conflicts", such as braking and evasive manoeuvres. Again PSIONs will be used to record observed events and the rate of these could be compared with similar events modelled by PARAMICS. Note that this recording of conflicts does not follow formal traffic conflicts survey techniques such as those developed by Perkins (1969).

2.6.8 Delays at Constraints (roadworks, one-lane bridges)

Data collected recently for a study of the SH1 Hurunui one-lane bridge in north Canterbury would be used to demonstrate how PARAMICS can be employed for such a scenario (the two other models have no equivalent ability). If necessary, additional data could be collected at the site using PSION Organisers.

Similarly, delay data could be collected from a roadworks operation that involves significant closure of traffic lanes, e.g. resealing. The results could be compared with a PARAMICS model set up to replicate the scenario. This exercise would depend on the timing and availability of suitable local sites.

2.6.9 Estimation of Fuel Consumption

Instrumented vehicles would be used to drive over a route with varying terrain to assess the rate of fuel consumption for given situations. The Nissan Pulsar, operated by Opus Central Laboratories, and a rental car and truck with onboard computer would be used for this exercise. Two runs would be made in each vehicle from Lower Hutt via the Rimutaka Saddle to Masterton and back. The fuel consumed would be noted at a number of intermediate points, allowing for trip break-up by terrain. Travel times and time spent following would also be noted by the occupants at these points to allow for accurate calibration of the models later. Vehicle power parameters could also be assessed by testing the uphill speed performance in a similar manner to the gradient surveys in Section 2.6.2. This information could then be compared with predicted fuel consumption from the simulation models, when only the surveyed vehicle types are included.

3. Field Data Collection and Simulation

Task 1, described in the previous section, identified an ideal project survey plan for assessment of the various simulation packages. Potential sites were identified through a combination of means and surveyed as required to collect adequate field data. Site selection was largely based on a desktop analysis of road geometry data for State Highways in the North Canterbury region, coupled with assessment gleaned from "Highway Information Sheets", drive-over inspections, and personal experience. Appendix A.1 lists the sites identified for field surveys, although not all had surveys carried out on them.

In the end, 31 different surveys were carried out at 23 locations. However the sheer quantity of data collected, coupled with the subsequent difficulties encountered setting up some models, limited the amount of analysis that was possible. As a result, many of the following discussions do not include full quantitative results, and are based on what could be ascertained from the model testing (i.e. results are subject to confirmation after further analysis).

Each model was assessed for ease of setting up the required scenarios and (where possible) how well it represents the true situation as shown by the field data. From this analysis, conclusions were drawn as to the applicability of each model for New Zealand conditions.

Because there is a lot of commonality in developing models with any particular package, a general discussion is presented first on each package, outlining recurring issues raised when developing the various models. The field surveys and model development for specific aspects are then described in more detail, followed by an overall evaluation and discussion.

3.1 Simulation Model Development

This section documents some of the main features of each package that required attention when developing models for this research. In particular, the relatively "new" models to New Zealand rural modelling, TWOPAS and PARAMICS, required some adaptation for local use and this is discussed at length.

3.1.1 TRARR

Currently, of the packages studied, TRARR is the best suited to quick set-up of a road model, largely due to its use of geometry data similar to that collected by Transit New Zealand. The existing experience within New Zealand, including the author's, of developing previous TRARR models makes for a familiarity that users of the other packages still have to cultivate.

Because of its previous use in New Zealand for rural modelling, little was needed to modify TRARR's input files for use in this study; the reader is referred to other reports such as Hoban *et al* (1991) and Koorey & Gu (2001) for more detailed information. In particular, the vehicle parameters and traffic stream proportions used for this study are those derived from the findings of Tate (1995) for New Zealand conditions.

Section 2.3.1 mentioned some of the existing problems experienced with TRARR. It should be noted that many of the issues regarding its links to external inputs and outputs (e.g. production of project evaluation benefits) are common to all of the packages tested. For those that are specific to the modelling itself, either it was not possible to test TRARR against some attributes or a workaround had to be used.

One issue mentioned was the use of available geometry data. Since the original RGDAS geometry data was collected in New Zealand (in 1992), Transit New Zealand now collects road geometry data as part of its other high-speed data collection contracts. As a result, the information is now stored in a different format, albeit a more useful one for relating to State Highway route positions. An automated database routine has been developed to convert this data into an RGDAS format suitable for importing into TRARR.

The TRARR 4 front-end (T4.EXE) was only used for the road importing and creation process. The raw data files were then run directly with the TRARR "engine" (TRARR.EXE) using a series of batch programs. This enabled multiple road and traffic combinations to be modelled very quickly. Another custom-developed software tool was then used to extract the required information from the output files and combine them in a spreadsheet for analysis.

3.1.2 TWOPAS

The TWOPAS front-end, UCBRURAL, requires similar input data to that required by TRARR, making it easy to comprehend for many New Zealand analysts. In fact, this similarity stems from the legacy of UCBRURAL as a tool originally designed for running either TRARR or TWOPAS for research purposes, hence the need for presenting similar input data. Future versions of TWOPAS interfaces will not have this restriction, enabling more TWOPAS-specific features to be available for configuring.

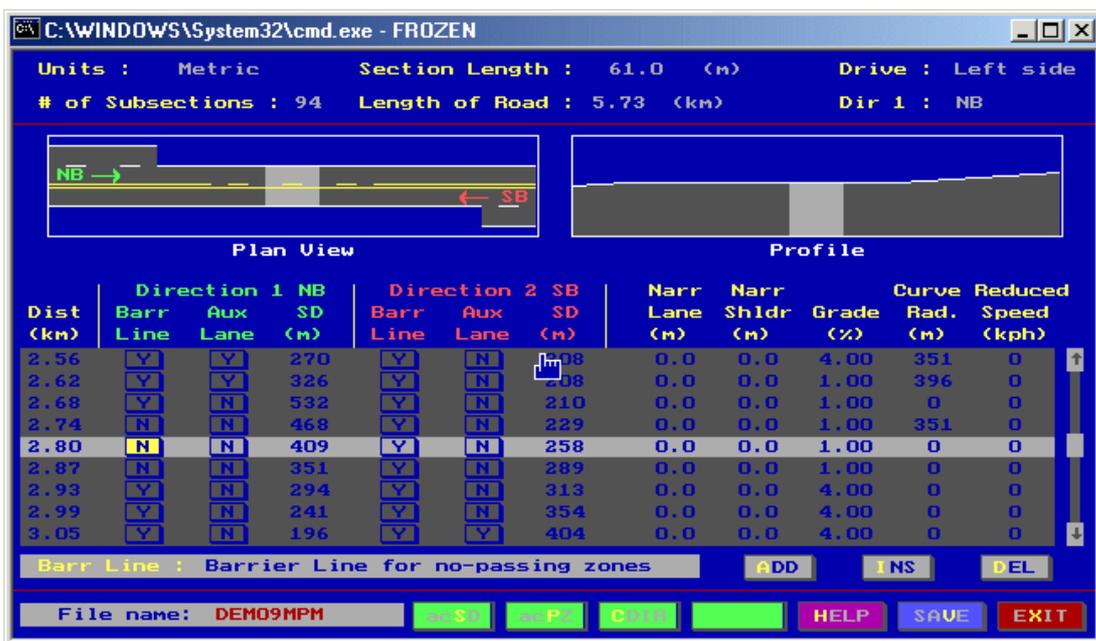
Like TRARR, TWOPAS defines its road data in terms of equal-length road sections, though it allows flexibility in the length of these sections to suit the analyst. Although (like TRARR) the default section length is 100 m, lengths can range between 16-1600 m (0.01-1.00 mile). However a maximum of 1200 sections can be modelled, which may affect the length chosen for projects covering a long distance. This flexibility means that more detailed geometry data could be incorporated into the models than allowed for by TRARR (e.g. 20 m sections), or it could be used with greater lengths for strategic planning purposes (e.g. 500 m). It should be noted that while the actual TWOPAS engine will accept variable-length geometric elements, fixed-length editing is presented by the front-end for simplicity.

Currently TWOPAS does not provide an easy way to automatically import road geometry data into its front-end editor UCBRURAL (TRARRIN.EXE), because of the use of binary (machine-coded) data files. The TWOPAS engine itself (TWOPAS98.EXE) does use a text-format file (TWOPAS.INP), so a procedure could be developed that automatically produces files of this format. However this is complicated by the fact that (unlike TRARR) the input file has no built-in explanation of each data item and the units are all Imperial (e.g. mph, ft, etc). The resulting file still could not be edited using the front-end editor, so all TWOPAS

modelling would need to be directly with the TWOPAS engine. It appears that the new Windows version of TWOPAS will resolve this problem.

To counter this somewhat, one very useful facility that the UCBRURAL road editor has is the option to automatically repeat the geometric and cross-section attributes entered for a road section to all identical road sections following it. This enables data for long straights, gradients and curves to be quickly entered, element by element (referred to as a "zone-based" editing system by TWOPAS). The TWOPAS road editor can also automatically determine no-passing zones if desired, based on the sight distances specified. Figure 3.1 shows how some of these features are specified in the UCBRURAL road editor.

Figure 3.1 TWOPAS 98 Road Editor



A number of minor limitations are present in the TWOPAS simulations (Leiman *et al* 1998). Firstly sight distances are restricted to no more than 609m (2000 ft). Although this should be a sufficient distance to allow overtaking, it is not clear if it hinders the potential amount of overtaking that could be possible. Some New Zealand models may also find it difficult to comply with TWOPAS's minimum shoulder widths of 0.2 m and maximum grades of 10%. The model is also limited to a maximum simulation time of 120 minutes (7200 s). For a road with relatively low volumes, not enough vehicles could be modelled in that time; similar work with TRARR (Tate 1995) suggests that at least 1000 vehicles need to be simulated, due to the random numbers used, to get a sufficiently good level of precision.

TWOPAS has by default 5 classes of car, 4 classes of truck and 4 classes of "recreational vehicle" (RV). In comparison to the other models, this seems a bit limiting, particularly in terms of truck varieties. It is acknowledged however that cars and light vehicles tend to dominate most rural traffic streams and hence will carry the most weight on project benefits. But the influence of trucks on the rest of the traffic is significant, and it may be worthwhile recoding some RV classes as truck types. Because of the minimal documentation regarding the parameters specified for each vehicle type, no attempt has so far been made to produce a New Zealand-specific

vehicle fleet for TWOPAS. The mismatch with other common groupings such as TRARR's 18 categories and Transit New Zealand's 14-class scheme also requires some thought about an appropriate matching process.

Many of TWOPAS's underlying parameters are now stored outside the program in TWPSUSER.TDF (similar to those stored in TRARR's VEHS file), and UCBRURAL allows the user to use custom-values for these instead of the defaults. However the documenting of these parameters is very limited, making it difficult to know the full effect of changing many of them. Two that were tested were those relating to driver behaviour at the start and end of auxiliary lanes (parameters JPS and LFAV), to better reflect New Zealand design and driver practice.

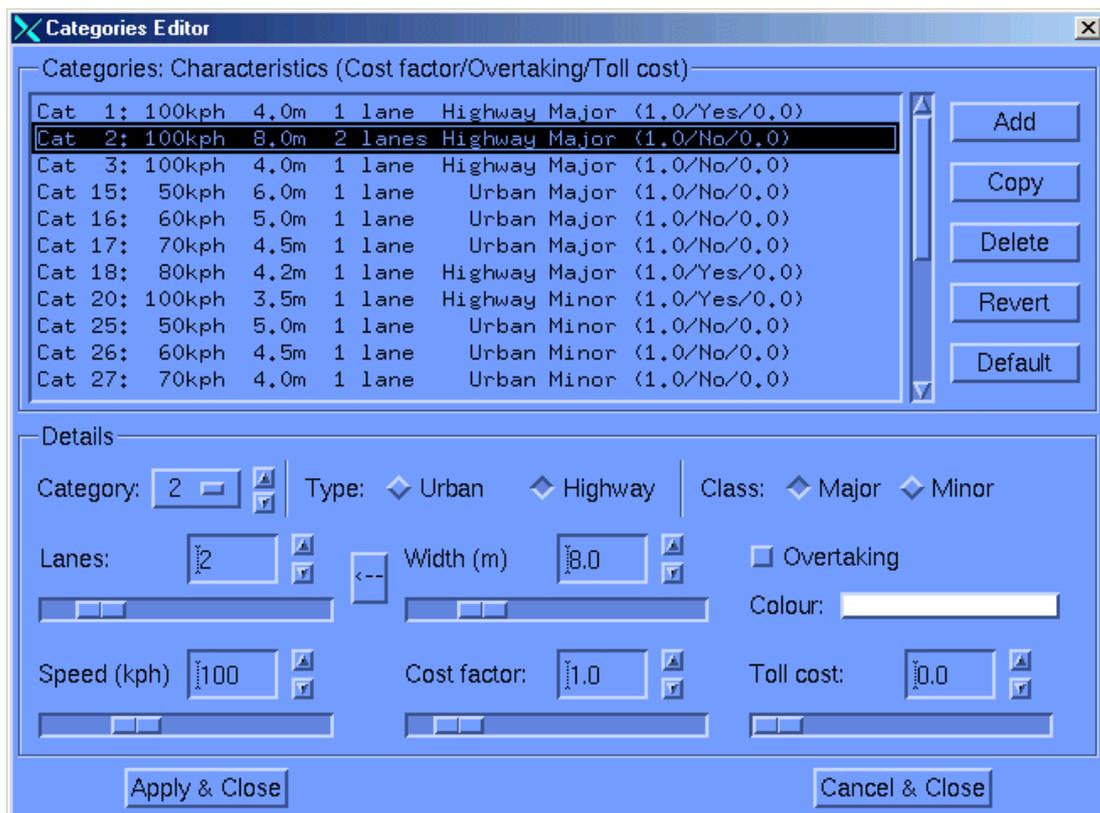
The ability to run multiple traffic simulations on a road automatically is a useful facility for quickly obtaining data over a wide range of traffic volumes. It would be better however if multiple road files (e.g. project options) could also be run simultaneously, as is possible with TRARR 4. UCBRURAL then allows the results to be exported to a text file for easy importing into a spreadsheet. More detailed output can still be viewed in the corresponding *.OUT files if required; TWOPAS provides an extensive array of report details.

3.1.3 PARAMICS

PARAMICS uses a series of simple text files to store different attributes of its network. For a typical rural highway, the most relevant ones are NODES, LINKS, CENTRES, and ANNOTATION. These map out the geometry of the road sections in the model, with the latter providing any textual or graphical background information to display as well.

Default road link categories are provided to specify basic attributes of each link (speed, width, number of lanes, overtaking allowed, etc). The standard ones provided are geared towards urban and motorway networks, and are hence largely irrelevant for this project. For the purposes of this project, a specific set of rural-based link categories have been produced and these are listed in Appendix A.2. More specific link attributes need to be set for links with certain functions (e.g. approaching intersections and passing lanes) and Appendix A.3 tables the values recommended. Figure 3.2 shows the link category editor with some of the new categories set up for this project.

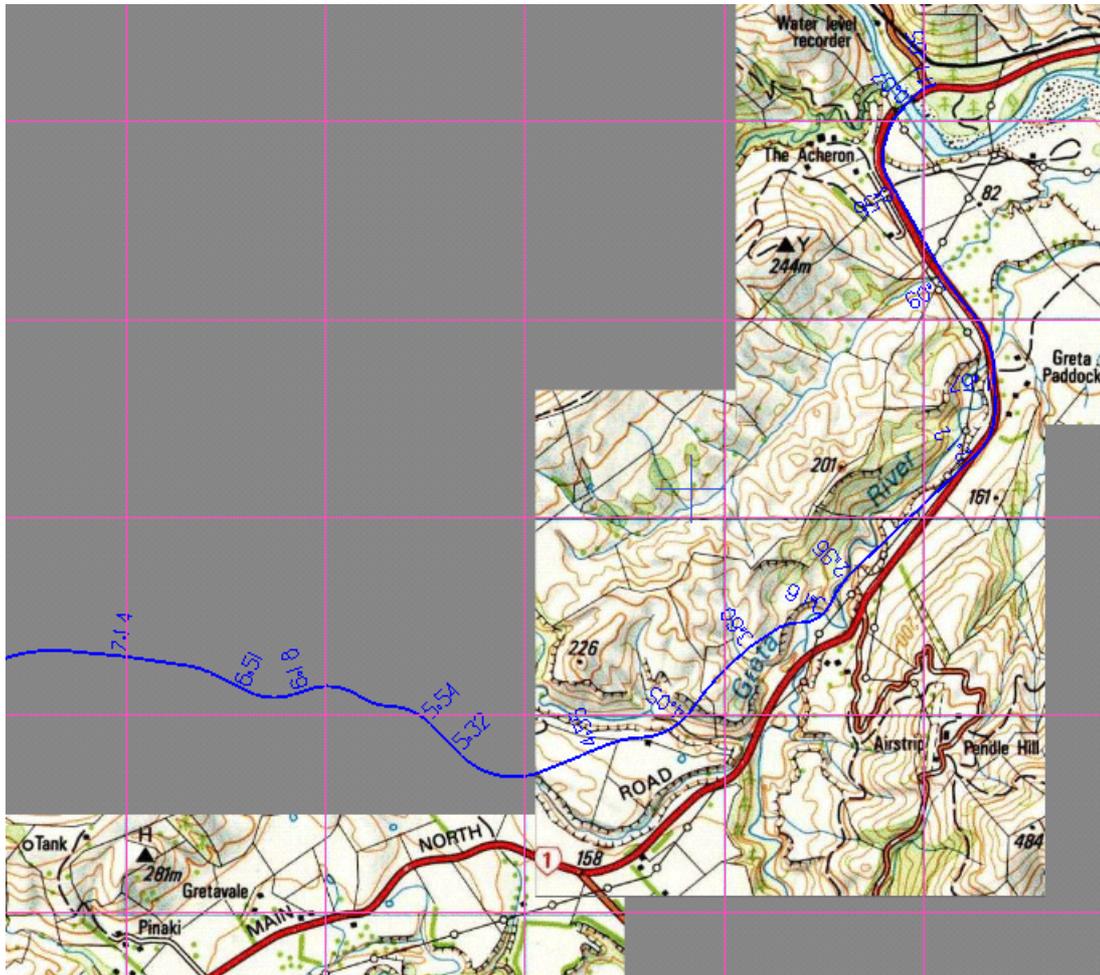
Figure 3.2 PARAMICS road link categories



Road sections are defined as a series of straights and curves between fixed nodes. This "elements" approach differs from the format provided for State Highway geometry data, which contains geometry data at fixed (10 m) intervals. Specifying a series of individual links for each 10 m section would greatly increase the complexity of the modelled network and limit the accuracy of built-in procedures such as forward sight-distance checking. The data therefore needs to be rationalised into longer lengths that identify the underlying tangents and curves along the highway.

An automated procedure was developed that took 10 m geometry data, converted it into a series of geometric elements, and exported this information to the PARAMICS data files. For the data available, no continuous grid reference data was available, so co-ordinate positions were inferred from horizontal curvature data. As Figure 3.3 shows, the resulting plotted route (blue line) identified the various "kinks" of the highway very well. However the ongoing errors inherent in the curvature estimation meant that the highway position got progressively further away from the true location (as indicated by the red route on the underlying map). In terms of accuracy of modelling, this will probably not affect the results greatly as they are largely focused on localised road conditions. However it would be preferable to be able to "rubber-band" the resulting plot back to the true co-ordinates to allow overlaying the model with other topographic information. Some manual concatenation of similarly aligned adjacent very-short links into single longer links may also be preferable from a modelling point of view.

Figure 3.3 Road Alignment in PARAMICS using Automatic Road Geometry Creation

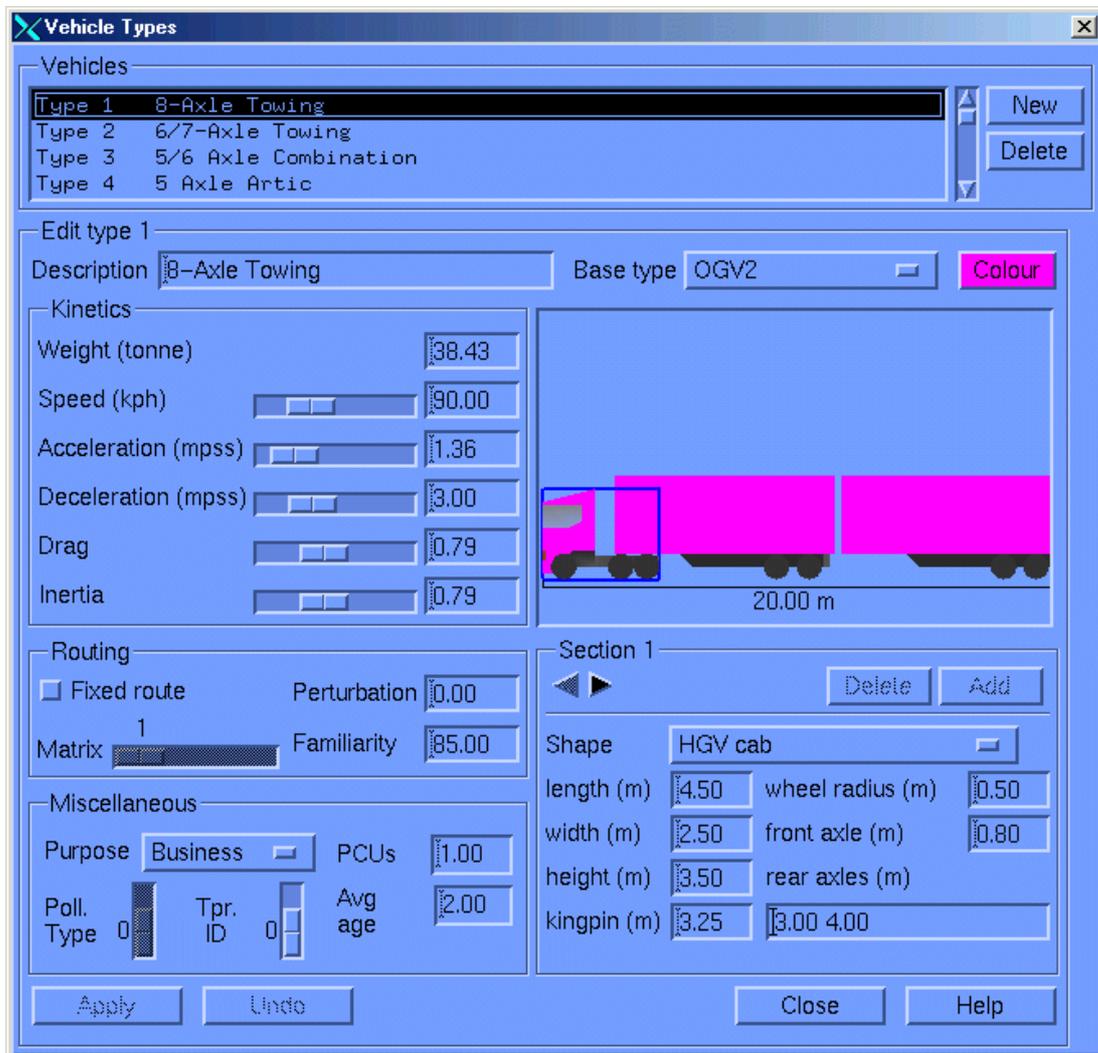


The alternative approach is to use available mapping information to create the required highway alignment. Sufficiently detailed aerial photos or topographic maps can be overlaid onto the PARAMICS network, and the highway alignment then created over the top. For this exercise, 1:50,000 maps from the Land Information New Zealand (LINZ) TopoMap database were used to produce the required background data. LINZ also has high-resolution ortho-photos for much of the country available on its website, and some of these were also tested. Many road controlling authorities have aerial photos of even higher resolution. While this approach makes for easy setup of route alignments, care needs to be taken to ensure that horizontal curves reflect the true constraints on site (e.g. if there is an isolated "kink" within a curve). For a particularly winding alignment, this approach is also very laborious.

PARAMICS allows you to specify a huge number of vehicle types if desired (up to 512). Figure 3.4 shows the dialog window for editing vehicle details; note that a graphical representation of each vehicle type can also be specified for visual modelling. For traditional PARAMICS models, the default types are categorised by both vehicle configuration (car, truck, etc) and journey purpose (home-to-work, leisure, etc). However, for rural modelling, vehicle performance is more important, particularly where highway geometry and open road speeds are involved. To obtain

comparable measures with the other models, a vehicle set has been created that replicates TRARR's 18 categories; Appendix A.4 lists the details.

Figure 3.4 PARAMICS vehicle type definition



Unlike the other models, PARAMICS does not directly specify mean and standard deviation desired speeds for vehicle speed distributions. Free vehicle speeds in PARAMICS are controlled by a number of factors:

- The target speed for the particular vehicle type (generally representing the mean desired free speed)
- The default speed for the particular link category (generally equivalent to a speed limit)
- The link speed for a specific link (particularly curved links)
- The gradient of the link
- The transition between adjacent links (particularly when "kinked")

SIAS (2000) outlines the basic method used to determine vehicle speeds on "highway" links:

- 1) Take the link speed parameter as a starting value. (*Note: This is usually the default speed for the link category unless it has been modified for a specific link*)
- 2) Assume that mean behaviour is to exceed this speed slightly (*sic*), as follows:
 - up to 7% (linearly spread over lanes) in highway links affected by "hazards" (e.g. intersections)
 - up to 20% (linearly spread over lanes) in highway links with no hazard
- 3) If necessary, cap this at the vehicle type's target speed. This is now the mean speed for that vehicle type on that link.
- 4) Find a spread of speeds. On multi-lane highways assume that outside ("nearside") lanes have more speed variation than central ("offside") lanes. The variation V is $V = A + B/[\text{lane\#}]$ (%), where
 - $A = 4, B = 8$ for links with hazards = 8% single/central lane, 12% outside
 - $A = 10, B = 20$ for other links = 20% single/central lane, 30% outside
- 5) Apply the aggression distribution to the mean and variation to find a speed for this particular vehicle on this link. (*Note: this is a probabilistic distribution that can be adjusted by the user, e.g. normal or uniform distributions*)
- 6) Try to drive along the link at that speed. The actual achieved speed will depend on interaction with other vehicles and end of link manoeuvring.

Other model features such as gradients and intersection controls will also affect the final speed selection. The above methodology appears to have a number of quirks not entirely suited to New Zealand highway modelling. The assumption of mean speeds up to 20% above the speed limit does not match the typical NZ mean rural speed of approximately 102 km/h on long straight 2-lane 100 km/h zones (LTSA 2001a). However this can be countered by using lower target vehicle-type speeds. Similarly, a typical coefficient of variation (sd/mean) for NZ rural sites is about 12%, leading to speeds within, say, three standard deviations of the mean (99.7% of all values) of $\pm 36\%$. It is not clear how well this will fit with the variation and speed distribution used by PARAMICS. Comparisons between two-lane and four-lane roads with the same alignment and speed limits and with little traffic interaction also give the counter-intuitive finding that mean speeds are faster on the two-lane road.

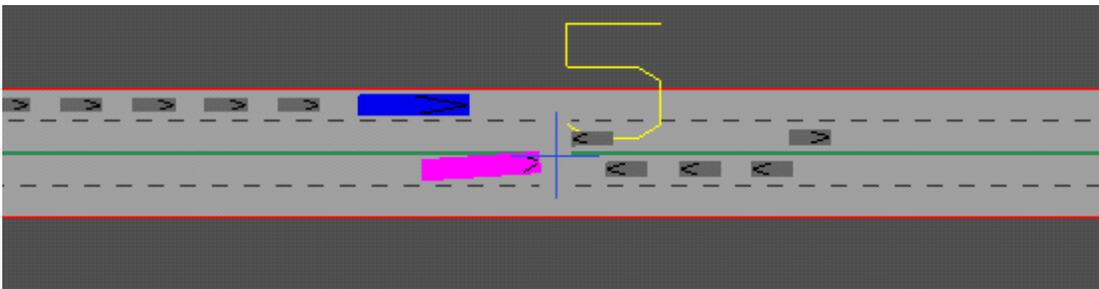
Speed restrictions may also apply to vehicles moving between links. Although a smooth transition between successive road elements is not required, a lack of one may affect the speed that vehicles travel at when traversing the link boundary. PARAMICS links have "stopline" points defined at each end that vehicles must pass through. Depending on the exact location and orientation of these stoplines, vehicles may have to slow down to physically move from the exit stopline of one link to the entry stopline of the next link.

As with other traffic network models, zones are created at the end of each route and trip demands specified for each pair of origin/destination zones. For a simple linear highway, only two zones and demands each would be needed, but the method allows additional side roads to also be introduced if necessary. A number of different time periods can be modelled consecutively, each with a different traffic demand. This enables an entire rural traffic profile to be built up and modelled in one run if required.

A number of operational difficulties were encountered in the development of the various PARAMICS models. The most serious was that, on a regular basis when running a simulation, a vehicle would stop for no apparent reason (and often appear to "park" in the opposing lane). This made collecting accurate simulation run data rather difficult, because the wayward vehicles had to be manually "destroyed" promptly. The problem was invariably at a node connection (mid-block, not a junction), but no obvious problems with respect to stoplines, kerbpoints, etc were apparent. Subsequent discussion with local PARAMICS users confirmed that this problem has been encountered before and SIAS are planning to fix it in the next release.

Figure 3.5 shows an example of such an occurrence at a node (5). Vehicle directions are evident by the "V" at the front of each vehicle. Note that a vehicle in each direction is stopped in the opposing traffic lanes (although opposing traffic drives right through them as indicated by the rightmost vehicle). As a result, queues have started to form in each direction "behind" the errant vehicles, although some vehicles prove to be alert enough to change lanes and avoid them. Often on multi-lane highways the lead vehicle that has halted will then, after some seconds delay, start up again and continue on normally, leaving the next vehicle to crawl up to the front and repeat the process. Discussion with SIAS technical staff has so far failed to uncover the reason behind the problem.

Figure 3.5 Example of PARAMICS "stalling" error



Other issues encountered seem to highlight the program's origins in urban and motorway modelling. For example, a (one-way) link with >2 exits (e.g. crossroads) will be automatically switched from being categorised as a "Highway" link to an "Urban" one. However in New Zealand there are a number of rural crossroads, and it is not clear what the effect of this change is on vehicle behaviour. Similar problems exist representing typical driver behaviour in situations like passing lane merges and right-turn bays at intersections.

PARAMICS sends results to a number of different files, depending on the type of data being collected. The results of each logged simulation run are also placed in separate directories. As a result, a more manual process was necessary to obtain the required information for subsequent analysis. However, for regular use, it could be possible to develop a simple software tool to extract the required information from each file and collate it in a more efficient manner.

3.2 Analysis of Model Attributes

A series of field surveys was carried out to collect typical data for each attribute assessed. In addition, some existing data from previous studies were also re-used.

3.2.1 Curve Speed Prediction

Data collected from two curves in a previous study of curve advisory speeds (Koorey *et al* 2002) were re-examined in this study. The two sites, with posted advisory speeds of 45 and 75 km/h respectively, had speeds recorded approaching and travelling through the curve in each direction, for approximately 24 hours. Other sites had only speeds within the curve collected, but were also examined for simple validation.

Further speed data were collected using a speed digitector, provided by the LTSA. Two thin tribo-electric wires were placed across the road 25m apart and connected to a control box that displayed speeds between the wires in a selected direction. A significant advantage of the digitector system is that the observer can be located some distance away from the actual road, which (coupled with the inconspicuous wires used) minimises potential bias by drivers aware that they are being observed. The observed speeds, vehicle types and travel directions were recorded using a hand-held Psion Organiser, and the data was downloaded later for analysis.

To create the models, horizontal alignment data for the sites was required. RAMM geometry data were the primary source used for this, although for PARAMICS mapping data were also used.

TRARR determines curve speeds by specifying different road speed indices for each road section, indicating the expected reduction from the desired mean speed for each vehicle. The road speed index values are based on Australian rural speed research and are determined based on observed speed changes at different radii. It appears however that the relative coarseness of TRARR road sections (100m intervals) masks extremes in road curvature, which suggests that it may over-estimate section speeds in some circumstances.

TWOPAS calculates minimum and maximum curve speed values, based on lateral acceleration (although no details are given). A normal speed distribution is then fitted within this range (with the extremes representing ± 3 standard deviations away from the mean speed). The accuracy for each road section will be dependent on the coarseness of the section interval used and the radius specified.

In PARAMICS, if a link is designated as curved, editing of the link radius will automatically change the link speed from the default value for that link type (the link speed can also be changed manually). Calculated curve speeds, V , for a given curve radius, R , are based on drivers keeping their lateral acceleration (V^2/R) no higher than $1/3g$, which is relatively high in terms of design standards but quite feasible for modern cars.

Table 3.1 compares the predictions of the various packages to the observed field data. In setting up the models the mean desired speeds were based on New Zealand speed survey findings and no calibration of these was carried out. For PARAMICS,

the curve link speeds were set to the posted advisory speeds. Note that originally the PARAMICS curves were created using an underlying map layout and automatically generated link speeds 10 km/h higher than that posted, with mean modelled curve speeds approximately 12 km/h higher (figures shown in parentheses).

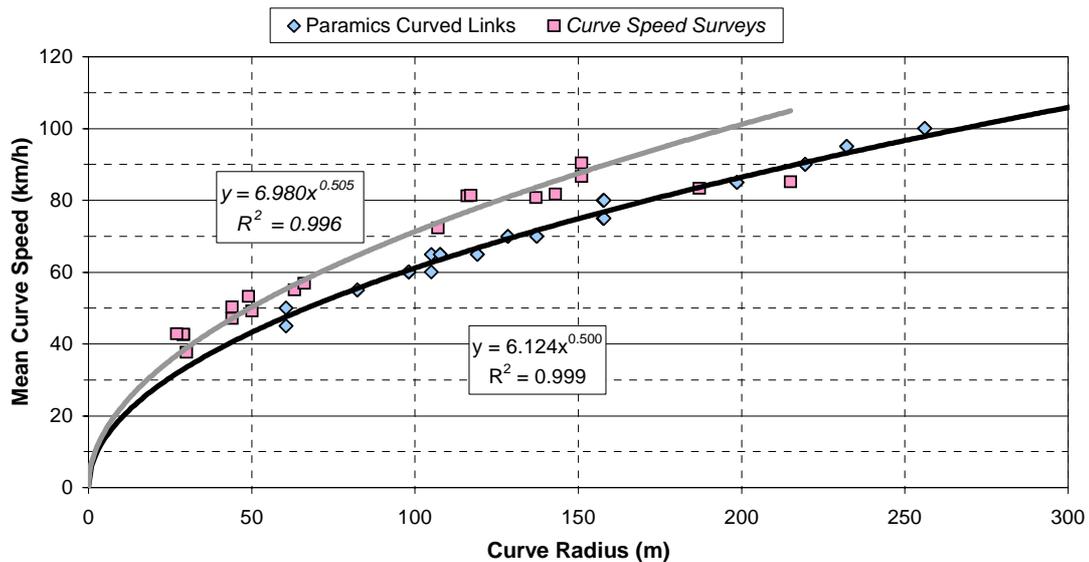
Table 3.1 Comparison of Curve Mean Speed Predictions

Site	Direction	Vehicle Type	Mean of Minimum Curve Speed (km/h)			
			Field Data	TRARR	TWOPAS	PARAMICS
SH2 Masterton 75km/h Advisory Speed, Level Terrain	Southbound	Light Veh	91.7	91.4	82.5	87.7
		Heavy Veh	88.2	84.8	85.9	(99.0)
	Northbound	Light Veh	88.3	86.7	74.3	83.9
		Heavy Veh	80.4	79.2	85.0	(98.7)
SH2 Kaitoke 45km/h Advisory Speed, Winding Terrain	Southbound	Light Veh	49.8	79.1	66.0	51.9
		Heavy Veh	45.2	75.6	67.9	(63.3)
	Northbound	Light Veh	53.4	82.0	64.0	54.0
		Heavy Veh	52.3	77.9	55.2	(65.2)

Note: no disaggregation by vehicle type produced in PARAMICS

While TRARR proved to be very accurate with the higher-speed site, it was poor with the lower-speed one. Conversely TWOPAS was better at the lower-speed site than the higher one; it is also interesting to note that the heavy vehicle speeds were generally higher. The fact that neither was particularly accurate with the lower speed site may reflect the problems in using a 100 m-section interval in terrain where the curvature and gradient is changing significantly very often. It suggests that site-specific speed surveys may be needed to confirm the validity of models with significant curves. The PARAMICS curves performed much better, although the ability to specify link speeds assists here. When based on mapping data instead, they may suffer a similar problem to the other models; the radius of the arcs used by PARAMICS tends to be somewhat greater than the minimum measured radius.

As well as the two curves of interest, the approaches to them included a number of curves of varying radii. The specified curved link speeds in PARAMICS were compared with mean observed curve speeds collected as part of a separate research study (Koorey *et al* 2002). Figure 3.6 plots the comparison. Note that the PARAMICS speeds are rounded to the nearest 5 km/h; as a result the speeds for the inside and outside curve directions may differ slightly. As expected the best-fit relationship through these points is exactly proportional to the square root of the radius, with the coefficient equivalent to a centrifugal force of 0.3g. A similar plot for the curve speed survey data gives a speed relationship about 14% higher.

Figure 3.6 Comparison of PARAMICS Link Curve Speeds with Field Surveys

Two caveats should apply to these findings:

- The radius points for the curve speed surveys are the minimum radii found within the curve. Most curves were not very consistent throughout the arc, and so the typical arc radius may have been higher. In theory however, the minimum radius should represent the point of greatest friction demand.
- The mean observed survey speeds are not directly compatible with the curve link speeds. As stated previously, the initial mean vehicle speed is assumed to be some proportion higher than the given link speed.

Given these considerations, it is reasonable to assume that the PARAMICS curve link speeds are appropriate for rural modelling here. The figures in Table 3.1 would suggest however that precise specification of the curve radius or advisory speed is needed to achieve this.

3.2.2 Vehicle Performance and Gradient Speed Prediction

Speed surveys were carried out on two significant straight gradients in the Canterbury region. Each site had a long straight on the bottom approach to enable relatively high entry speeds into the gradients. A laser gun was used to record speeds of uphill traffic near the bottom of the hill, while a digitector recorded their speeds approximately 300m further up the hill. A few downhill speeds were also recorded to identify any self-limiting of speeds by drivers. Detailed classification data was also noted (particularly for various truck types) and all data was recorded using a Psion Organiser. The lower than expected approach speeds suggest that drivers may have been affected by the presence of the parked survey vehicle, although for this exercise it is the relative difference in speeds along the gradient that is significant in being able to calculate vehicle power.

Given the resulting speed pairs and information about the gradient, an estimate of the vehicles' power/weight ratios could be determined. This information and general vehicle descriptions could be used to specify the vehicle characteristics to be

modelled. Additional background information was obtained from other sources such as Bennett (1994).

Unfortunately the sites available were not on high volume routes; therefore only a limited data sample could be collected in the time available. In particular, many of the various heavy vehicle types often had only one or two vehicles recorded. The differing performance of various heavy vehicle configurations makes it difficult to aggregate these. Therefore, only car speeds are presented below, with other model comparisons based on field data from Bennett (1994). At one site, continuing difficulties with the digitector equipment also hampered survey efforts, requiring three trips to complete the survey successfully. Data from the other site also suggested that the gradient was not significant enough to make a notable reduction in the speeds of many vehicles.

Table 3.2 compares modelled speeds in TRARR and TWOPAS on an 8-10% gradient at SH75 Takamatua. Generally the estimated power/weight ratios were much higher than those indicated by the field data and from previous research by Bennett (1994), although the heavy vehicles were more realistic. TRARR's car classes in particular suffered little effect on speeds, although field data had found a 16 km/h mean drop in car speeds on this gradient.

Table 3.2 Comparison of Modelled Gradient Speeds at SH75 Takamatua

Mean Speeds (km/h)	Field Data	TWOPAS			TRARR				
	Car	Car	RV	Truck	Car	LCV	MCV	HCV1	HCV2
Approach Straight	-	100.6	96.2	90.4	100.5	94.1	91.3	90.4	90.6
Bottom of Hill	84.9	99.6	95.6	87.4	100.4	94.1	91.2	90.2	90.1
300m Up Hill	68.8	89.1	84.0	53.7	99.3	88.8	81.6	73.0	56.8
Downgrade	82.5	101.2	97.3	89.6	99.8	93.3	89.9	88.7	89.6

McLean (1991) described the work carried out to improve TRARR's gradient prediction equations. In general, the model relies on the HDM "steady-state" prediction algorithms described by Watanatada *et al* (1987). Downgrade speeds in particular were improved to reflect the speed limiting observed by many vehicles travelling downhill.

TWOPAS's vehicle performance parameters were updated relatively recently (Leiman *et al* 1998) to reflect the capabilities of the modern vehicle fleet. This has improved the prediction of its mechanistic-based gradient speed prediction, particularly for heavy vehicles. However, no downhill speed limiting appears to be in evidence, despite earlier incarnations of this model allowing for this (St John & Kobett 1978). TWOPAS does allow the specification of "crawl regions", where steady speeds by trucks and RVs can be stipulated; however this facility is not available via the front-end.

PARAMICS does not document how vehicle performance is affected on gradients. However the presence of parameters such as vehicle weight and drag suggest that the model is a typical mechanistic-based one. A test model on a long straight with a 10% gradient found that mean vehicle speeds dropped (from level speeds) by ~9 km/h on the up-grade and ~4 km/h on the down-grade. Bennett (1994) however suggests that

over the given length and grade mean speeds for even passenger cars should have fallen by ~20 km/h on the up-grade. This suggests again that vehicle performance factors in this model are over-estimated.

3.2.3 Two-Lane Bunching/Overtaking

Automated surveys of changes in vehicle bunching were collected along three routes of differing terrain (flat, rolling, mountainous). Each route of approximately 11-13 km in length included a number of passing lanes or slow vehicle bays. Four locations along each route were surveyed simultaneously using Metrocount classifiers that collected vehicle counts, speeds, classifications and volumes. The resulting data were summarised by traffic volume and the chosen routes modelled by simulation to compare the predicted and observed bunching changes.

While the automated surveys were being carried out, the same sections were also surveyed using number-plate surveys at each end (for mean travel times), and then repeatedly driven back and forth using the speed profiler (for within-trip speed variation). As well as establishing speeds and travel times from these, the number of passes could also be inferred over the study length. The corresponding overtaking rates can then be compared with those predicted by the simulation models. The observed rates however would be conservative, due to incomplete sampling and matching rates while recording vehicle plates.

One logistical problem with the automated surveys was that the traffic contractor placed a number of the recorders at incorrect locations. While in some cases this was not of great significance, in others the recorder was moved to the other side of a notable town or side road. The limited survey programme timeframe and the need to undertake the other manual surveys at the same time precluded repeating these surveys, so the resulting data had to be used, albeit with some caution.

Additional surveys were attempted to determine accepted gaps in clear sight distance ahead and oncoming vehicles that drivers will accept for overtaking. The observation vehicle was fitted with the speed profiler device and attempted to travel at a slower-than-normal speed to attract overtaking by following traffic. Various "events" relating to surrounding vehicle manoeuvres (e.g. oncoming traffic, vehicles passing) and the road environment (e.g. sight distance restrictions, reference points) were recorded along the way.

For gaps in opposing vehicles a long straight section, driven back and forth, was used to collect data. Meanwhile, for sight distance restrictions, an adjacent series of curves and short straights was driven along. Unfortunately the sites proved to be relatively limited in terms of traffic volumes and passing demand was low, even when the test vehicle's speed was more than 20 km/h below normal mean speeds. An alternative high volume site was surveyed as well for gaps in oncoming traffic, however a surprisingly high level of "patience" was observed by following traffic even when generous gaps and relatively low speeds were combined. These surveys also suffered from response problems in the computer recording software (e.g. pressed buttons would not record an event), making it very difficult to identify all of the critical events. As a result these data have not been investigated further.

TRARR uses a series of vehicle "states" to determine whether a vehicle is free, following, overtaking, and so forth. Depending on the relative desired speeds and "aggressiveness" of bunched vehicles, a following vehicle may be "happy" to stay following or it may be waiting to overtake when sufficient passing distance is available. A comprehensive range of behavioural parameters is specified in the VEHS file for each vehicle type to enable overtaking behaviour to be modified, although the practicalities of doing this appropriately are probably beyond most users.

TWOPAS also contains a number of overtaking parameters in its TWPSUSER.TDF file. However the purpose of all of them is not immediately evident, and so adjustment at this stage is not recommended. A cursory examination of St John & Kobett (1978) suggests that many of them remain unchanged since the original development of this model in the 1970s.

The PARAMICS overtaking model is based on drivers looking up to two links away for oncoming traffic to determine whether adequate passing distance is available. While the two-link restriction is understandable from a computational point of view, in some cases this limits the forward sight distance available to a driver (e.g. where short links are required to match the underlying alignment). The other factors that affect driver overtaking (and also lane changing, car following, and gap acceptance) are the "aggression" and "awareness" parameters. It is not clear however from the documentation exactly how these influence the behaviours of interest.

3.2.4 Passing Lane and Four-Laning Operations

Number-plate surveys were carried out at each end of a long busy passing lane just south of Christchurch. An attempt was made to collect every number-plate where possible, although the sheer volume at times meant that "anonymous" plates were recorded at times (in hindsight, a video survey would have been more suitable for these volumes). From these data, a conservative estimate of the number of passes could be inferred over the passing lane length, and corresponding overtaking rates determined.

On the same site, separate observation surveys were also carried out to identify where the overtaking occurs within the passing lane. The passing lane length was subdivided in various sections and records kept of the number of vehicles changing lanes to left or right. One problem noted with this methodology is that it failed to identify the precise number of overtakings occurring, as vehicles often overtook multiple vehicles while in the right-hand lane. Again the data were compared with the simulation model predictions. Another difficulty identified when setting up TWOPAS models is that the ability to precisely specify observation points matching those in the field is constrained by the spacing of the road sections.

Table 3.3 compares the proportion of vehicles observed to be moving to the right hand lane (i.e. overtaking) at the start (taper) of the passing lanes. An interesting finding from the models is that TWOPAS and TRARR both significantly overestimated the number of vehicles that overtake at the beginning of a passing lane. This may be a consequence of the current New Zealand road marking scheme (where traffic is now directed to the left lane at the start of the passing lane), which

has been shown to increase the proportion that move left initially (Charlton *et al* 2001). TWOPAS allows driver lane preference to be specified, albeit only in simple "left/right/neither" terms. At the downstream end, an equal merge between lanes is not provided for in TWOPAS and towards the end of the passing lane all vehicles ultimately move into the preferred end lane.

PARAMICS too is strongly influenced by the form of the end merge taper, with vehicles preferring to move to the "end priority" lane from the start of the passing lane (unless sufficient intermediate links are created in between). No apparent "keep left unless overtaking" principle seems to be in action. Experimentation with different combinations of normal tapers and "wide start/end" tapers in PARAMICS found that all vehicles stayed in one lane at the beginning of the passing lane before considering overtaking. This is reflected in the table below, where different options were tried in each direction.

Table 3.3 Proportion of Vehicles Overtaking at Start of Passing Lane

SH1s RP365/6.9-7.4	Field	TRARR	TWOPAS	PARAMICS
Southbound	22.2%	34.9%	36.4%	100%
Northbound	21.3%	35.2%	39.5%	0%

Although the different methods of reporting where overtaking occurred made it difficult to compare the models and field data directly, all three models seemed to correctly identify a diminishing amount of overtaking occurring along the length of the passing lane. While both TRARR and TWOPAS somewhat overestimated the amount of overtaking occurring, PARAMICS showed a relatively low level of overtaking, as indicated by the observed behaviour above.

Attempts were also made to obtain automated data from the Christchurch Northern Motorway between Kaiapoi and Belfast to develop speed-volume relationships. However this dataset was not forthcoming, so a simple speed-flow comparison of the three models was carried out instead. Figure 3.7 shows some data collected on SH1 near Burnham, a very straight and level two-lane section with reasonably high volumes. The data shows a relatively moderate reduction in mean speed observed as one-way volumes increased to over 600 vehicles/hr (veh/h).

Figure 3.7 Speed-Flow Field Data from SH1 near Burnham

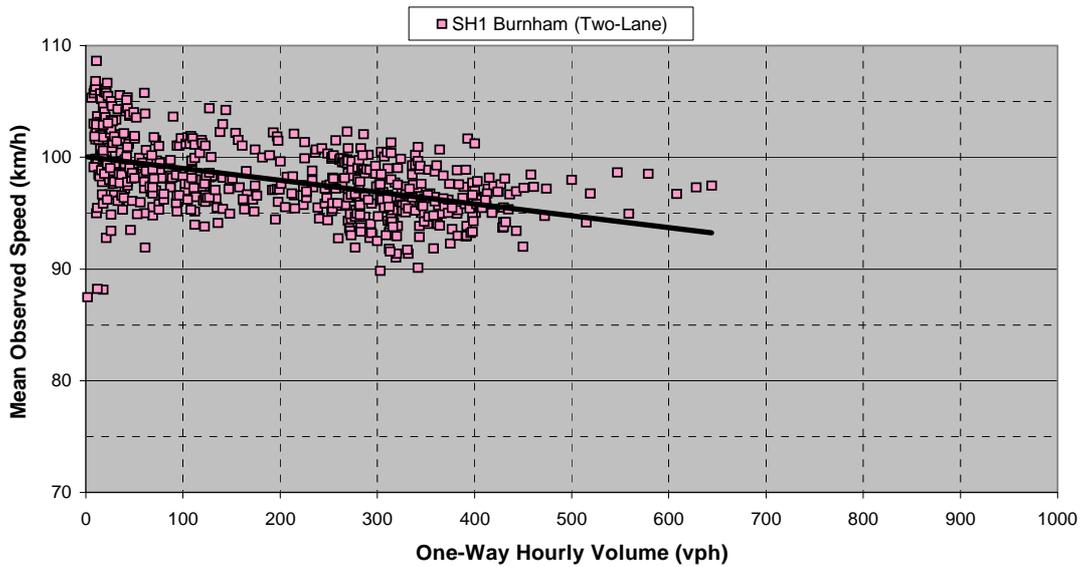


Figure 3.8 shows data points modelled by TRARR for both two-lane and four-lane straight and level road alignments, with similar traffic composition. The two-lane data shows a significantly greater reduction in mean travel speeds than that observed at Burnham. Meanwhile the four-lane results show the rather counter-intuitive finding of increasing mean speeds with volume.

Figure 3.8 Speed-Flow Data Modelled by TRARR

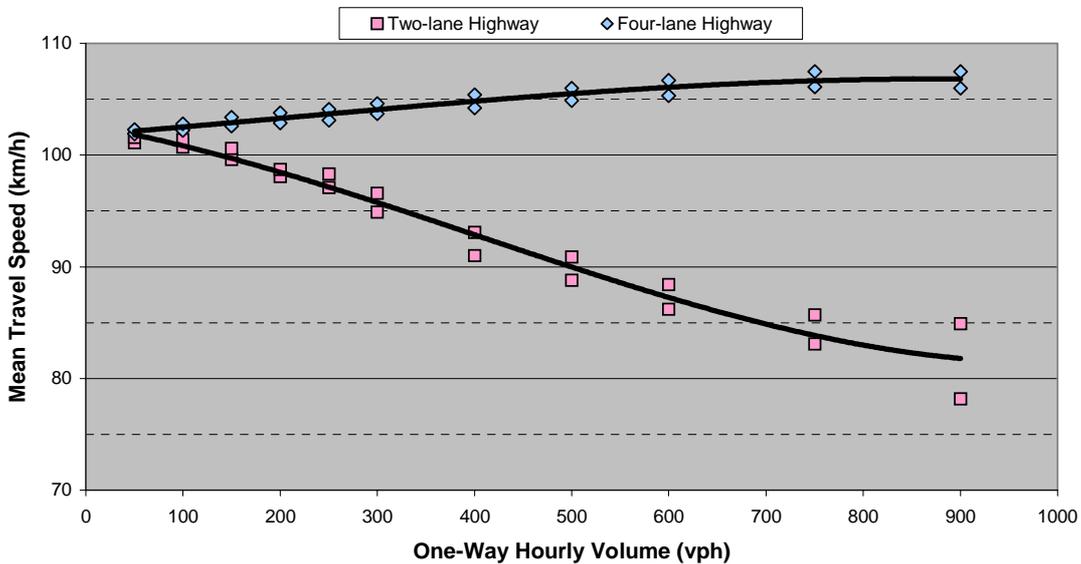


Figure 3.9 shows results from equivalent models using TWOPAS. The two-lane data is very similar to TRARR in its over-emphasised speed reductions with volume. The four-lane data however appears more realistic, except at 900 veh/h.

Figure 3.9 Speed-Flow Data Modelled by TWOPAS

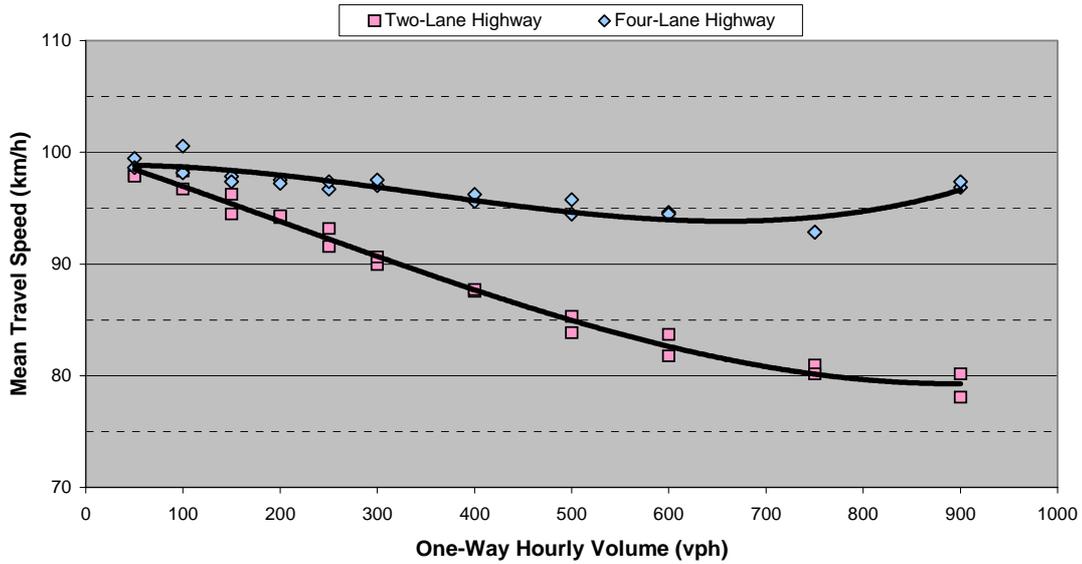
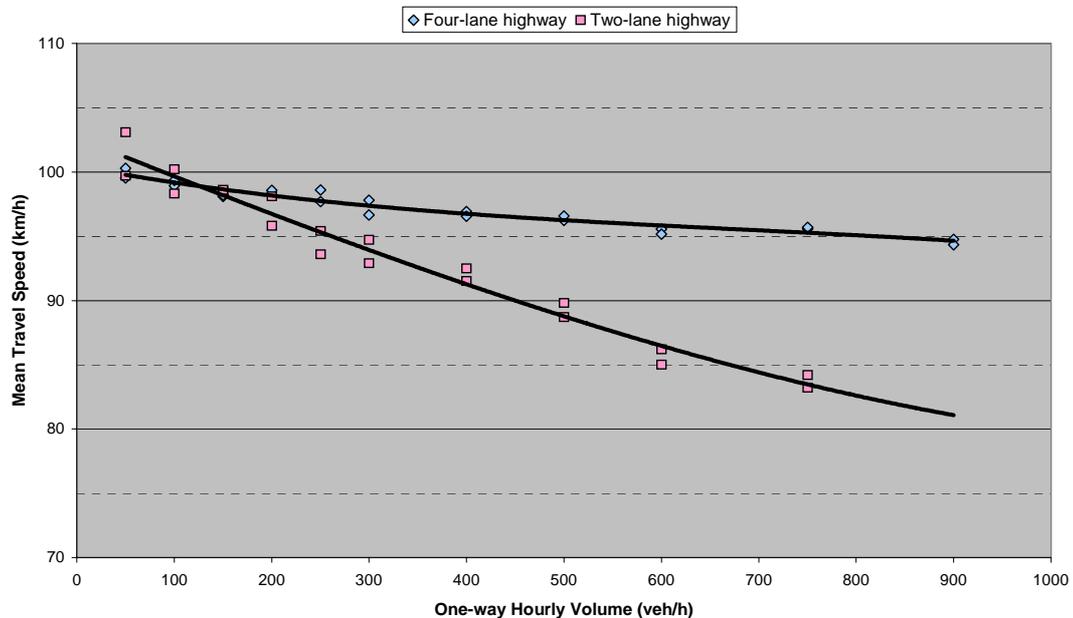


Figure 3.10 shows a very similar pattern from results modelled by PARAMICS. The four-laning relationship appears to be the most stable of the three models, although the speed calculations it uses produce the curious result at low volumes of lower speeds than the equivalent two-volume case. Attempts to examine PARAMICS at higher volumes ran into considerable "stalled vehicle" errors, particularly from 600 veh/h upwards. Indeed, no simulation run was spared this problem, requiring manual intervention to ensure meaningful results.

Figure 3.10 Speed-Flow Data Modelled by PARAMICS



It is interesting to note that all three models consistently produced a greater reduction in speed than that observed in the field. The one caveat is that near the observed traffic sites there are some passing lanes that may help to reduce the bunching (and hence slower speeds) when measured just down the road. Both TWOPAS and PARAMICS also produced relatively consistent (and plausible) speed-flow

relationships for four-lane situations, but clearly there is some aspect of TRARR's methodology that is not modelling these situations well.

3.2.5 Speed Limits and Roadside Development

Approaches to two small Canterbury towns with speed limits, Culverden and Kirwee (50 and 70 km/h respectively), were surveyed for how the mean free speeds change on approaching the township. Three automated VDAS tube counters were used to collect data some distance before the speed limit interface, at the interface, and after the interface. Vehicles with headways less than 7 seconds were ignored as not being sufficiently "free". Unfortunately, technical problems with one of the counters limited the surveys to just two speed points. Table 3.4 summarises the results from these two locations.

Table 3.4 Mean free speeds near small urban centres

Survey Locations	Direction	Vehicle Type	Mean Speed at Location (a)	Mean Speed at Location (b)	Speed Change
Culverden 50 km/h South side (a) 600m outside signs (b) at 100/50 km/h signs	Towards Speed Limit	Car	95.3	64.8	30.5
		Truck	86.1	61.2	24.9
	Away from Speed Limit	Car	92.0	66.4	25.6
		Truck	79.5	62.7	16.8
Kirwee 70 km/h East side (a) at 100/70 km/h signs (b) 200m inside signs	Towards Speed Limit	Car	82.5	72.1	10.4
		Truck	73.6	71.5	2.1
	Away from Speed Limit	Car	88.2	74.7	13.5
		Truck	83.0	76.0	7.0

These surveys demonstrate the difficulty in finding consistent patterns of vehicle speed behaviour around speed limit areas. Probably the most consistent finding is the fact that (higher speed) car speeds reduce more than truck speeds, leading to more uniform combined speed distributions in the speed-limited area.

Each of the models surveyed uses a different approach to modelling speed reduction areas. TRARR has no formal means of introducing limited speed zones, and so manual adjustments of "road speed indices" are necessary. These are used by TRARR to determine how fast different vehicles will travel, as a proportion of their desired free speed, and are normally used to identify curves and gradients. The process is not ideal, particularly as most speed indices affect different vehicle streams by disproportionate amounts. Shepherd (1994) provides details of the indices available.

TWOPAS allows the specification of "speed reduction zones". The mean speed for each zone is input, with the standard deviation scaled down from the default values by a similar proportion. In other (unrestricted) areas, traffic free speeds are dictated by the default vehicle desired speeds.

PARAMICS allows the specification of a "link speed" for each road link, with the prevailing posted speed limit usually the most suitable value. Mean vehicle speeds are then determined using the procedure outlined in Section 3.1.3. Unlike the other models, there is no distinction between limited and unlimited speed zones, i.e. there is no default link speed.

For calibration of models containing short urban areas, measurement of mean travel times through the area could be used to confirm that the model is using suitable travel speeds. It could be argued however that, for projects where the relative savings in travel time between options are important, it is not significant what speeds are used in a nearby town, so long as they are constant between options. Of more importance is likely to be the effect of a town on vehicle bunching, to properly reflect the benefits of downstream passing opportunities. Towns invariably cause a quite different speed distribution, provide limited passing opportunities, and may also introduce additional traffic interaction and other delays. Bunching surveys either side of significant urban areas should be used to confirm that the models accurately replicate this.

Other developments may also affect vehicle free speeds. Another survey was carried out to assess the effects on speed of a railway crossing on a long straight. A digitector was used to collect vehicle speeds at the crossing, while a laser gun recorded the same vehicles approximately 300m down the road (vehicles required by law to stop at a crossing were ignored). Although the methodology worked fairly well, it may have been affected slightly by some road works around the next corner north at the time of survey. Table 3.5 summarises the results, separated by direction and vehicle type.

Table 3.5 Mean free speeds near rural railway crossing (xing)

Direction	Vehicle Type	Mean Speed at xing	Mean Speed 300m from xing	Percentage Speed Drop
Southbound (towards xing)	Car	89.4	100.6	11%
	Truck	81.7	88.6	8%
Northbound (away from xing)	Car	88.7	93.6	5%
	Truck	81.6	81.3	-

The findings show statistically significant reductions in free speeds on approaching the crossing, although the picture is less clear for those travelling away from the crossing and towards the previously mentioned road works.

The significant point for this study is the fact that none of the models examined allows for features like this; hence localised surveying of such features would be required to determine a "speed reduction factor" to be applied in this area. Fortunately, because highways often run parallel to railway lines, many level crossings on highways tend to involve low-radius curves that will have a greater effect on vehicle speeds.

3.2.6 Road Width Effects

Surveys of mean free speeds were carried out at four locations on long straights with less than optimal lane width. Standard digitector speed surveys were used to collect the speed data. Unfortunately it wasn't possible to identify locations for surveys of varying widths along the same routes for a true comparison of width effects on the same vehicles. The relatively low traffic volumes also precluded getting ideal sample sizes in the time available; use of automated speed recorders may be a more pragmatic approach for future surveys.

No discernible evidence of narrow width effects was found, with mean free speeds for cars ranging between 96-104 km/h. For the lower-speed sites, there is also a suspicion that speeds may have been affected by the less-than-ideal location of the survey vehicle. However the sites were not significantly below the optimum width. For example, while the narrowest traffic lanes surveyed were only 3.1m, they were in conjunction with 0.6 m shoulders.

A similar survey was carried out for free speeds on a long, straight and narrow (6.7 m wide) bridge, taking particular note of whether opposing traffic was present. For comparison, a section of long straight good-width highway nearby was also surveyed. Table 3.6 summarises the findings. Although the free speeds at the "optimal" site were not as high as expected (possibly due to survey-detection bias), they are still typically 5-7 km/h higher than those at the narrow bridge, a statistically significant difference. It is likely that the "constraining" effects of the solid bridge parapets have a significant effect on vehicle speeds in this case, compared with the relatively open shoulders at other sites.

Table 3.6 Mean free speeds near a narrow bridge

Survey Locations	Direction	Vehicle Type	Mean Speed (km/h)	Standard Deviation (km/h)	Sample Size
SH1 RP303/3.0 North of Saltwater Creek <i>Good alignment 10m wide</i>	Southbound	Car	95.7	7.1	100
		Truck	87.0	7.5	33
	Northbound	Car	93.2	7.3	95
		Truck	85.5	6.6	20
SH1 RP303/6.7 Ashley River Bridge <i>6.7m wide 360m long</i>	Southbound	Car	88.1	9.0	150
		Truck	82.1	9.5	39
	Northbound	Car	87.6	9.9	176
		Truck	81.4	8.1	49

The researchers hypothesised that speeds on narrow roads and bridges might be somewhat dependent on whether there is opposing traffic at the time, particularly for wider trucks. Drivers may tend to drive slower if they perceive that an oncoming vehicle is closer to them, requiring more attention to vehicle control on their part. During the surveys, vehicles were categorised as "opposed" or "unopposed", depending on whether oncoming traffic was present around the time of the speed observation. However, analysis of the results showed no significant difference between the two groups; in fact in most cases the "opposed" groups had the higher mean speeds. This may reflect the fact that none of the sites was exceptionally narrow, with traffic lanes of at least 3m.

Only TWOPAS currently makes practical use of road widths in its model evaluation, as discussed in Section 2.2.4, and currently only for shoulder widths. This does not allow for the effect on speeds of any adjacent structure or clear zone either. PARAMICS allows link width specification but this only appears to be relevant for graphical representation. TRARR has no facility to specify road widths. For most rural modelling applications however (particularly on State Highways), this limitation in modelling is not likely to be a problem.

3.2.7 Assessment of Delays and Conflicts from Side Road Traffic

A rural T-junction and a rural crossroads were surveyed manually by observation to determine gaps accepted (and rejected) when turning or crossing. Both sites were level and on a good alignment (to avoid additional influences), with sufficient turning flows and turning lanes present. Electronic "TTM2000" data collection boards were used to record the various vehicle manoeuvres and their time of occurrence (to the nearest second only). The data were then processed to identify time gaps between relevant manoeuvres (e.g. right-turning vehicle waiting versus through-traffic passing).

The most recent version of PARAMICS now allows the specification of gap acceptance parameters for individual links. These cover the various crossing and merging manoeuvres both at junctions and in multi-lane situations. The default values use minimum headways of 3-4 seconds, yet the work by Parsonson *et al* (1996) suggests that at rural speeds, headways of 5-7 seconds are more appropriate. The collected field data also seems to indicate similar larger headways, and suggests that at high speeds drivers are more conscious of the danger of accepting an inappropriate gap. Therefore PARAMICS models should be adjusted accordingly when used for rural intersection work.

Handheld PSION Organisers were also used to record number plates for travel times over a 1.60 km section of highway surrounding one of the intersections. The results were then compared with an equivalent TRARR simulation of the same section (which couldn't specify the presence of an intersection). Table 3.7 compares the two measures.

Table 3.7 Mean travel times through an Intersection

Direction	Vehicle Type	Surveyed Travel Times	TRARR Travel Times	Difference (secs)
Southbound	Car	60.5	57.0	-4.5
	Truck	67.3	61.8	-5.5
Northbound	Car	58.2	57.1	-1.1
	Truck	62.0	61.8	-0.2

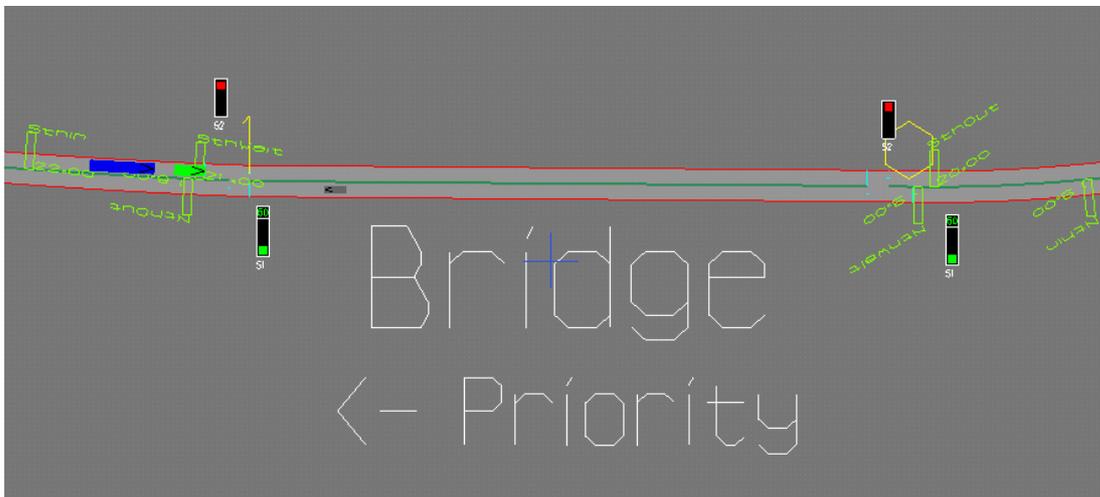
The results indicate that an additional intersection delay of up to 5 seconds is not being accounted for in a traditional linear road model like TRARR. For a comparative study of options however, where intersections are not likely to affect or be affected by the proposals, this difference may be cancelled out between options.

3.2.8 Delays at Constraints (road works, one-lane bridges)

Data collected recently for a study of the SH1 Hurunui one-lane bridge in North Canterbury was used to demonstrate how PARAMICS can be used for such a scenario (the two other models studied have no equivalent ability).

PARAMICS does not have a "one-lane bi-directional" link type, so two methods of analysis were tried. Firstly, a one-lane bridge model with vehicle-actuated (VA) signals controlling it was created. Some complexity of program logic is required to handle what is, on the surface, a relatively simple interaction between opposing flows. Three detector loops in each direction were used; approaching the bridge, at the stop position, and at the bridge exit position. This enabled PARAMICS to check whether any vehicles were still on the bridge (or in the case of the priority movement, almost on the bridge) before allowing traffic from the opposing direction to cross. The position of the approach detectors can be adjusted to suit sight distance considerations, and the method appeared to model one-lane bridge operations very realistically. Figure 3.11 shows the layout in operation (detectors shown by green rectangles); note the vehicles at the left approach stopped at the signal while traffic from the other (priority) direction crosses the "bridge" link.

Figure 3.11 PARAMICS One-Lane Bridge Model



A "priority intersection" style of one-lane bridge was also attempted. Effectively this was a junction of two one-way routes (at a very acute angle to each other), with one having "Give Way"-style priority over the other. The bridge space had to represent a very elongated intersection conflict area, with stop-lines set very far apart. However PARAMICS did not appear to properly recognise this layout and opposing vehicle conflicts along the bridge length were observed. Therefore only the VA signals model was pursued further.

Similarly, it would be feasible to model in PARAMICS a roadworks operation that involves significant closure of traffic lanes, e.g. resealing or rock blasting. Traffic control, either by signals or manual (stop/go) control could be programmed either on a fixed time or demand-responsive basis. For major works operations on busy highways, modelling of various traffic management options like this to determine an optimal strategy could be quite cost-effective.

3.2.9 Estimation of Fuel Consumption

The researchers had planned to carry out some instrumented drive-overs on a specific route to collect fuel consumption data for comparison. However considerable difficulties were encountered with the data recording equipment in one vehicle, and there was also doubt about the suitability of some rental vehicles for further surveys. As a result, the field investigation has not been successfully carried out and only a cursory assessment of the model capabilities is presented here.

TRARR has a built-in petrol/diesel consumption model, based on Australian research (Biggs 1988), the data being specified in the VEHS files. Fuel consumption for each vehicle group is reported as standard for the overall observed interval.

PARAMICS allows for the calculation of both fuel consumption and various pollutant emissions through the provision of a user-specified `pollution` data file. This enables vehicle types to be linked with various engine types (petrol/diesel, large/small, catalytic, etc). The pollution levels for each link or fuel consumption for each vehicle trip can be produced as outputs, but no automatic means of summarising this information over the network is apparent.

TWOPAS does not currently have a fuel consumption model, and it does not appear to have been considered in relevant documents.

3.3 Comparison of Packages

As discussed in Section 2, assessment of these simulation packages requires evaluation of both the technical ability (model accuracy) and the functional ability (model usability). A range of desired features under both categories has been identified and subsequently tested.

3.3.1 Accuracy of Prediction

Table 3.8 summarises the assessed correctness identified in each of the selected model features, after evaluation of each package in conjunction with field data and subjective experience. Note that although these assessments imply a reasonable level of model validity, calibration of a specific project with suitable field data is recommended.

Table 3.8 Assessment of Correctness of Selected Simulation Model Features

Rural Modelling Feature	TRARR 4	TWOPAS 98	PARAMICS '01
Curve Speed Prediction	22	22	22
Gradient Speed Prediction	1	22	22
Two-Lane Bunching/Overtaking	22	333	22
Passing Lane Overtaking	333	22	1
Speed-Flow Relationships	22	333	333
Speed Limits / Developments	1	22	22
Road Width Effects	-	22	1
Side Road Traffic	-	-	22
Delays at Constraints (roadworks, one-lane bridges)	-	-	22
Estimation of Fuel Consumption	?	?	?
Assessment of Safety / Conflicts	-	-	-

Key:

- 333 : excellent
- 22 : fair
- 1 : poor
- ? : unknown
- - : not available

The above table suggests that for most traditional rural modelling applications, TWOPAS is more robust than the alternatives, having benefited from the most recent rural highway research and development. PARAMICS shows acceptable performance in areas of more complex vehicle interaction, such as intersections and one-lane bridges, but does appear to need some adjustment of the defaults to represent the behaviour of typical New Zealand rural drivers in many situations. TRARR still provides an adequate performance in the basic road alignment and passing lane assessments that have been its main use in New Zealand over the past decade, but is limited beyond that.

3.3.2 Ease of Use

Table 3.9 summarises many of the specifications and features of each model. These were identified either through practical testing, or from related documentation.

Table 3.9 Comparison of Selected Simulation Models for Ease of Use

Feature/Attribute	TRARR 4	TWOPAS 98	PARAMICS '01
Max. highway lengths	Front-end limited to 50 km, longer lengths can be modelled directly	≤1200 equal-len. sections, incl. ≤150 curves, ≤100 speed limit zones, up to 48.3km (30 miles)	No limit (subject to memory/processor), up to 65536 nodes for normal version
Max. traffic volumes	Dependent on length modelled, up to ~1000 vehs in sim. at one time	up to 2000 veh/h, up to ~4000 vehs in sim. at one time, sim. times limited to 120 mins	Standard licence allows up to 1000 vehs in sim. at one time; can be extended
Road data import	Can use RGTRA pre-processor to import RGDAS geometry data	No facility currently available	No built-in facility, but can edit data files directly.
Vehicle types	18 types, fully specifiable	13 types, specifiable within car/truck/RV groups	up to 512 types, fully specifiable, limited graphical representation
Roadway editing	Text column editing with simple graphical indication of roadway	Text column editing with simple graphical indication of roadway. "Zone editing" option	Graphical on-screen manipulation, with attribute editing in dialog windows
Multiple periods/traffic flows	Can run multiple ROAD and TRAF files	Can run multiple Traffic files in front-end	Specify multiple time periods
Error/range checking of data	Only run-time checks	Provided throughout front-end	Some warnings and errors flagged
Customisation of outputs	Coarse specification of additional outputs	Either detailed or summarised output formats only	Flexible specification of a wide range of output measures
Use of outputs for PEM work	Well formatted for quick use	Hard copies only in Imperial units	Fairly flexible to produce required data
Field data use	Can enter initial bunching	Can enter initial bunching	Can use traffic counts for matrix estimation
Text-based input/output files	Yes, with extensive annotation	Not for front-end, simulation engine uses a text input file	Yes, but with limited annotation
Visual interface	DOS-based menu front-end	DOS-based menu front-end	Windows/Unix program with graphical editing
Graphical display of data	Plots of mean speeds, travel times, percent following	Plots of mean speeds, percent following, number of passes	2D/3D animation of simulation, Statistical plots of outputs
Online Help	Context-sensitive help within front-end	Context-sensitive help within front-end	Limited help with some dialog boxes
Manuals, Documentation	Basic manual with front-end, earlier more detailed manuals also available	Nothing supplied with software, separate manuals difficult to obtain	Extensive paper/electronic reference guide and installation guide

In addition, it is pertinent to note that run times for TRARR/TWOPAS simulations are very fast; only a few seconds for a typical model on modern fast PCs. By contrast, PARAMICS is still relatively slow, even when run in (non-graphical) batch mode, generally taking some minutes to simulate a few hours of traffic (this is also dependent on the number of time-slices specified per second). PARAMICS run times were also made worse by the "stalled vehicle" problems that left extra vehicles queued in the system, but in practice they are still of a fairly reasonable duration for working purposes.

Many New Zealand rural highway projects are based on alignment data from either RAMM road geometry or roading design software (e.g. MXROAD). Therefore, the lack of a means to import this data directly into TWOPAS is a significant problem. For any significantly long project length, manual entry of road data could be considerably tedious (although the zone-based data entry system helps). Although PARAMICS also has no direct means of entering numerical data, overlays can be used to develop an alignment reasonably quickly or the data files can be manipulated directly by some automated means.

3.4 Discussion

The ultimate test of any model is not whether its various aspects involve state-of-the-art theory or have user-friendly features. Rather, it is whether the simulation package can carry out an adequate evaluation of a particular project, in the most practical and accurate manner. It is likely that, given the range of various rural roading projects carried out, certain models will be better suited to some applications than others.

Table 3.10 sets out a suggested ranking of suitability of the models tested (and other tools identified) for a range of typical rural project applications. This is based on the investigations in this project as well as previous research and experience of the author. The likely ability of each package to adequately model the situation has been considered, as well as the ease of entering and extracting the required data. For example, curve and gradient speed prediction is likely to be of more significance on a realignment project than on a simple passing lane project, where overtaking prediction is more important. In some cases, only limited assessment has been possible to date, and further investigation may suggest a change in rankings.

In the case of PARAMICS, the "stalled vehicle" bug may prove problematic, at least until an update is released. However, generally the findings that were able to be collected from PARAMICS have been taken into account when assessing the model's suitability.

A list of known alternative methods of analysis is also presented in Table 3.10 for comparison. Full assessment of these was not possible in this project, but they include some relatively simpler (i.e. less costly and time-consuming) methods that may be appropriate at least at the scoping stage of many projects. For some of the more complex project types, other network models similar to PARAMICS may be just as appropriate. In the case of highway safety assessment, alternative methods should definitely be looked at, and Section 4 discusses some of these further.

It is notable that, while some project types are well served by modelling tools (e.g. passing lanes), others are still not well supported, or at least not for New Zealand situations. As mentioned earlier, highway safety assessment in particular is not well covered at all by these kinds of models, and Section 4 discusses some alternatives. For other areas, there may be scope for further research to develop suitable analysis tools for the industry.

The other thing to note is that each of the three main models investigated appears to have particular strengths over the others. In the short term this suggests that it would be worth encouraging the use of different packages on different projects, to obtain

the most appropriate project evaluation and to develop experience by practitioners. Agencies like Transit New Zealand may have to take the lead in introducing the packages to the roading industry by holding technical workshops on how to use them for various project applications. Such an approach would also have merit for urban modelling, where a plethora of options now exist with limited guidance as to their suitability.

In the long term it may be preferable to look at improving the "gaps" in the performance of some models so that they can cover a wider range of applications. This is particularly so for those areas where TRARR is currently the most suitable package, despite its older heritage. Often only TRARR's usability with New Zealand data gives it the edge in some cases, despite less robust model outputs.

Table 3.10 Suitability of Selected Simulation Models for various Rural Project Types(most suitable tool indicated in **bold**)

Project Type	TRARR 4	TWOPAS 98	PARAMICS '01	Alternative Methods	Comment
Simple (tack-on) Passing Lane	YYY	YYY	Y	PEM, TRB (2000)	Simplified procedure available in PEM (from Koorey <i>et al</i> 1999)
Passing Opps Strategic Study	YY	YY	Y	TRB (2000)	Transit NZ are developing procedures (BCHF 2001)
Slow Vehicle Bay	YY	Y	-	-	Refer to Koorey & Gu (2001) for guidance
Two-Lane Highway Realignment	YYY	YY	-	-	
Strategic Study Speed Profiles	Y	YY	-	-	Refer to Bennett (1994) for guidance
Overtaking/Sight Distance Review	Y	Y	-	RGTRA, I-Spy	
Four-Lane Highway Construction	Y	Y	YY	?	Capacity effects modelled by a number of network/freeway packages
Rural Intersection Assessment	-	?	Y	SIDRA	Future TWOPAS version should have this feature
Expressway Interchange	-	-	YY	?	Various network micro-simulation packages available
Small Town Bypass	Y	Y	YY	?	May be more suited to network modelling depending on layout
Shape Correction	-	-	-	-	Usually justify on safety/maintenance effects only
Seal/Bridge Widening	-	Y	-	PEM	Usually justify on safety effects only
One-Lane Bridge Replacement	-	-	YY	Saunders (1988)	
Temp. Traffic Control Delays	-	-	Y	-	Simplified guidance provided in new Transit NZ Code of Practice
Highway Safety Assessment	-	-	-	IHSDM, etc	Refer to Section 4 of this report

Key:

- YYY : very suitable
- YY : suitable
- Y : may be suitable
- ? : unknown
- - : not suitable

There are some caveats on the recommendations in Table 3.10:

- As with any modelling, sufficient field data is required to set up and accurately calibrate the base model.
- New Zealand-based traffic and vehicle data should be used with overseas-based models, as opposed to the defaults supplied with the program. The TRARR defaults developed for New Zealand by Tate (1995) are a good base for working with other models.
- Any results derived from a computer model should be subjectively reviewed by independent means for reasonableness (e.g. expected order of magnitude).

Hopefully, with further future development of TWOPAS and PARAMICS, these models will become even more useful for the various rural projects investigated in New Zealand. Feedback from New Zealand practitioners to the model developers will no doubt help the cause too.

4. Review of IHSDM and Related Safety Models

The rural road modelling framework suggested in Task 1 identified "Crash Risk" as a key output. When evaluating existing models however, the lack of safety performance measures is a key omission. A review of other safety performance tools available is therefore pertinent.

The review considered what aspects of these tools could be relevant here and what may need to be changed in order to use them here (e.g. differing standards). Consideration of how the underlying research could be incorporated into any future development of the simulation models examined above is also discussed.

The main tool identified is IHSDM, described in detail in Section 4.2.1. A similar review will also be made of other sufficiently developed rural safety models identified worldwide that could be applied here.

4.1 Literature Review of Safety Model Research

Generally New Zealand's existing crash analysis procedures are static "crash rate" models that relate typical crash rates and environmental modifying factors to actual traffic volumes. For project evaluation, existing analysis is usually as prescribed in Transfund New Zealand's *Project Evaluation Manual* (Transfund 2001). Cenek *et al* (1997) investigated the relationship between crashes and road geometry further than most, using Poisson crash risk models to estimate the effects of changes in geometry. More recently, Turner (2001) produced detailed models for predicting various intersection and mid-block crash rates based on traffic volumes.

Another potential approach is to use micro-simulation to analyse driver/vehicle behaviour and identify the frequency of situations that put road users at more risk than others. Because of the relatively rare nature of crashes, it is not expected that these models would necessarily simulate a vehicle crashing. Rather, proxies for unsafe behaviour can be used to assess likely crash rates, e.g. the number of aborted overtaking manoeuvres (as determined by changes in simulated vehicle intentions or "states"), or the number of vehicles exceeding the "safe" curve speed (the definition of which can vary greatly). This "traffic conflicts" approach has been applied for over two decades now to intersection-related crashes; however its application to mid-block situations is still relatively untapped (with some reason).

Fildes & Lee (1992) noted that, when considering safety, there is a distinction between features or treatments that affect the likelihood of being involved in a crash (crash involvement) and those that affect the likelihood of sustaining an injury given a crash (crash consequence). This is important when assessing the relative effects of highway features both on-road (e.g. curvature, crossfall) and off-road (e.g. drains, safety barriers). A safety model, for example, may need to separately consider the likelihood of running off the road (which in itself may be harmless) and the likelihood of subsequently hitting an object or rolling over.

The discussion below highlights some of the key issues identified in developing road safety models. Even this review is only scratching the surface of the many inter-

related factors; some other aspects of rural simulation models previously discussed (Task 1) also have safety implications. Further issues are also considered in the review of road safety models in Section 4.2.

4.1.1 Effects of Road Geometry and Environmental Features

A key distinction between the assessment of urban and rural road safety is the importance that roading features have in determining the likely crash rates of rural highways. In an urban environment, drivers are usually more constrained by either speed limits or other road users. The distinction shows up in the greater number of single-vehicle crashes on rural roads, and the influence that road features have on both the likelihood and severity of these crashes. At higher speeds, sight distances also become more important when considering crashes involving multiple vehicles.

Cenek *et al* (1997) examined the relationship between crashes and road geometry, using over 8000 km (single direction) of rural New Zealand State Highway traffic, geometry and crash data (divided into 200 m sections). Poisson regression models were derived to describe the relationship between variables, and to determine the relative risk between different road environments. Distinctive patterns emerged, such as the increasing crash risk as the absolute horizontal curvature or absolute gradient increased.

Austrroads (2000) examined nine lengths of highway in Australia and related geometric attributes such as pavement width and gradient with recorded crash rates. Although some trends were evident, such as increasing crash rates with increased horizontal curvature, the analysis appeared to suffer from not combining results of different highways, leading to smaller subgroup samples and noticeable variation among results. One important difference to the previous study by Cenek *et al* (1997) is that the roads were divided to produce reasonably uniform sections in terms of geometry, resulting in sections of varying length. Assuming that all relevant data can be equally divided in this way (e.g. crashes), this approach is intuitively more useful than sections of consistent length but variable geometry within.

Nicholson & Gibbons (2000) investigated the effects of sight distance on driver speeds on a hilly road alignment in New Zealand. They found that a large proportion of drivers were travelling too fast to stop in the available sight distance. Crash numbers were also correlated to the areas where speeds were found to be excessive for the available sight distance. Drivers appeared to be more influenced by the level of discomfort experienced while driving around a curve.

Levison *et al* (2001) suggested that drivers make one of a number of assumptions when presented with a limited sight distance situation, such as a curve:

- Drivers familiar with the road may drive according to the remembered alignment
- Drivers may assume a long straight just beyond the visible range

- Drivers may assume a possible hazard just outside the visible range
- Drivers may assume that the unseen geometry will be similar to the current alignment

The assumption used has implications for what speed a driver will choose, free of any traffic constraints. It is important therefore to identify what proportion of drivers fall into each category, although it is not immediately clear how this might be achieved accurately.

4.1.2 Speed and Safety

A common thread across many safety issues is the relative speeds of the vehicles involved. This has implications for both the likelihood and severity of crashes on rural roads. For example, a large variance in vehicle speeds within a traffic stream appears to increase the likelihood of vehicle interaction and associated rear-end or overtaking crashes, while a greater travelling speed at the time of collision increases the expected severity of a crash (Fildes & Lee 1992). It is important therefore to have a good understanding of likely speed distributions at an area under investigation.

Fitzpatrick & Collins (2000) outlined a methodology for predicting vehicle speeds on rural two-lane highways. Starting with the desired speed, it identified any curve or gradient limitations on speeds and then attempted to adjust speeds along the highway, using typical acceleration/deceleration rates, to match these limitations. The approach produced a fairly simply derived speed profile along the highway that could then be applied to various issues such as safety and vehicle operating costs. A similar methodology for New Zealand highways was previously developed by Bennett (1994) and is discussed in more detail in Section 2.2.1.

A common safety issue is the consistency of vehicle speed profiles with the surrounding speed environments. This has been shown to have significant effects on the overall safety of a rural route (Koorey & Tate 1997). Koorey & Tate used road geometry data to determine predicted speeds for each 10 m road element. By calculating rolling averages over short and long lengths (e.g. 100 m vs 1000 m), a speed profile could be determined and compared against a surrounding speed environment. Cross-analysis with the crash rates for the same sections showed a clear pattern of increasing crashes as the difference in these two measures increased.

4.1.3 Traffic Conflicts Research

Crashes are relatively rare events, given the number of vehicles that can pass a point without incident. This often makes it hard to assess the comparative safety of a particular roading feature from historical crash data alone. A research area that has been developed over the past 30 years is that of "traffic conflicts techniques" (TCTs) whereby observers record the incidence of certain vehicle conflicts and from this infer the expected safety performance of a site. TCT was widely investigated and promoted in the US and Europe during the 1970's and 80's. In New Zealand a workshop in 1980 introduced the concepts (NRB 1980), but TCT has not been used widely here.

Perkins & Harris (1967) pioneered this technique and defined a traffic conflict as occurring when "a driver takes evasive action, brakes or weaves, to avoid a collision"

(Perkins 1969). Subsequent studies have refined this definition, and various countries have adopted slightly different procedures, but the essence has remained the same. Attempts to relate traffic conflict numbers with crash numbers have met with varying success, although this may be a consequence of often inaccurate crash data collection. Older & Shippey (1977) also pointed out that the technique assumes that crashes are preceded by evasive action; yet filmed evidence shows that this is not always the case (e.g. hazard not noticed, driver fatigue).

To date, traffic conflicts research has largely concentrated on intersections, for which it is easier to identify and collect sufficient numbers of conflicts in a practical amount of time. It is a more difficult proposition to try to use similar techniques for relatively low-volume rural highway sections, particularly given the greater incidence of single-vehicle crashes. Indeed, Güttinger (1977) questioned whether conflict observation is possible in the case of "one-sided" (*sic*) crashes, such as collisions with objects. As a result, little research has explored this area in detail.

One exception was the work in Finland reported by Kulmala (1982), which considered rural features. Three "crawler" lanes were replaced by overtaking lanes and conflicts observed (it is not clear exactly what type of conflicts were looked for). Although conflicts increased after the first two weeks, observations three months after the change showed a notable (~50%) reduction. Locally, similar conflict observation techniques have been applied to the merge areas of slow vehicle bays on SH29 (Nicholson & Brough 2000) to determine the priority rankings for treatment.

The above techniques are based on observations at fixed locations. Some researchers have investigated conflicts along a route. Risser & Schützenhöfer (1984) reported on a study conducted in Austria recording traffic conflicts in moving vehicles. The aim was to find out typical drivers' errors resulting from unadjusted behaviour and often leading to traffic conflicts. 200 subjects drove a standardised route, with two observers in the cars collecting data. They included near-misses in the absence of other road-users and deviations from the normal road area.

Similarly, Charlesworth & Cairney (1988) investigated "unsafe driving actions" (UDAs). These included following too close, travelling too fast for conditions, turning too wide or sharply, crossing lane lines, and improper braking or evasive action. An analysis of crash data identified key UDAs; some techniques to observe these behaviours in the normal driving population were then piloted. This included moving car-following techniques on rural routes while recording dangerous overtaking, lane encroachment and speeding. LTSA's crash database could be used to identify key UDAs reported in crashes here, for subsequent observation.

Another way of examining traffic conflicts is to consider the number of "conflict opportunities" rather than the number of actual conflicts. For example, two vehicles approaching each other have the opportunity for a head-on conflict, but in most cases will pass safely. Kaub (1992) used this approach to estimate passing-related crashes. He used a "Statistically Probable Conflict Opportunity" (SPCO) crash model that related the probability of conflict opportunities with the probability of a crash occurring. A linear relationship between the two was usually sufficient. For passing, the probability of a conflict was defined as:

$$P(\text{Conflict}) = P(\text{Passing}) \times P(\text{Opposed})$$

where

$P(\text{Passing})$ = the likelihood of same-direction vehicles interacting, based on volume, speeds, etc

$P(\text{Opposed})$ = the likelihood of opposing traffic, based on opposing volume, overtaking time, etc

This approach has appeal in that all of the required data (volumes, speeds, crash numbers, etc) are readily available. Similar conflict opportunity models could be developed for other crash situations, such as lost-control and head-on crashes. The key difficulty is in identifying the features that must be included in the model. Some sites may have specific deficiencies that are causing a greater than normal crash rate and these would need to be incorporated. The above equation also implies independence between the two contributing probabilities when it is very likely that this is not the case (e.g. opposing traffic volumes).

Steyer *et al* (2000) described another interesting approach to the problem of predicting safety on rural two-lane curves. A "driving conflict technique" was developed that takes into account the appearance of the curve to the driver, the consistency of the alignment, and the predicted driving behaviour (speed, lateral placement, etc). Comparison of these parameters with the crash record at each curve allows for relationships to be inferred. Further work is required to validate the method in the field, but it appears to be a promising means of assessing non-intersection conflicts.

4.1.4 Relating Crash History with Crash Predictions

One problem in trying to predict crashes at a particular location is how to take into account every single aspect of the site's geometry and other features. A site may, for example, have a certain combination of features that produce a less safe environment, but this may not be easily captured by recording of standard parameters such as road width and curvature. Conversely, a site may be safer than expected, perhaps because its appearance makes drivers take more care. While a more detailed crash prediction model could try to identify each of the features that contribute to the relative safety of the site, it becomes more difficult to do so with any precision once the major features have been identified.

A method to try to resolve this is to combine the existing crash history at the site with the predicted crashes for a typical site of this nature. This allows the expected crash rate to be scaled up or down to allow for localised effects. The most common approach is known as the Empirical Bayes method, alluding to the use of Bayesian probability theory.

Hauer (1997) outlines the basic methodology, assuming that crashes at a site are Poisson distributed (i.e. mean equals variance). Consider a site with a recorded history of K crashes over a known period. A crash prediction model for similar sites produces estimates of the mean and variance at this site as $E\{\kappa\}$ and $VAR\{\kappa\}$ over the same period. The expected crash estimates (given the crash history K) can be calculated as:

$$E\{\kappa|K\} = \alpha \times E\{\kappa\} + (1-\alpha) \times K$$
$$VAR\{\kappa|K\} = (1-\alpha) \times E\{\kappa|K\}$$

where

$$\alpha = 1 / [1 + VAR\{\kappa\} / E\{\kappa\}]$$

It can be seen that more variable crash prediction (e.g. $VAR\{\kappa\} \gg E\{\kappa\}$) results in a lower weighting on the crash prediction model and more emphasis on the crash history. More complex calculations can also be derived for situations where a variety of crash history periods are used.

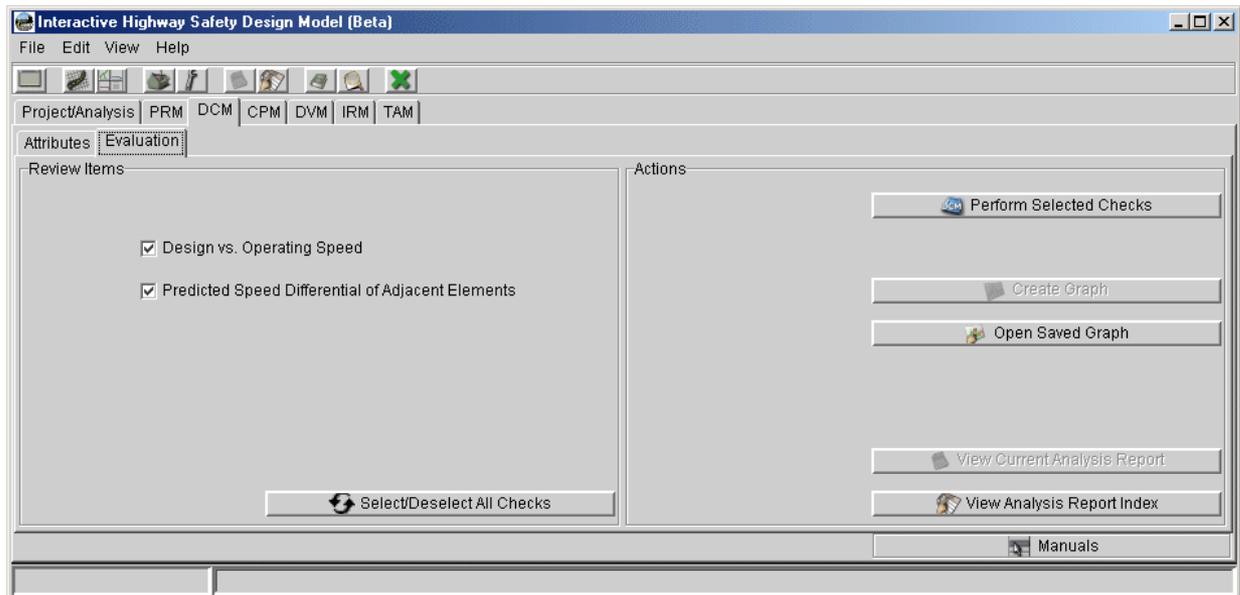
4.2 Available Road Safety Models

The simulation models examined in the previous chapters were designed specifically for evaluation of efficiency issues, e.g. travel time savings and reductions in time spent following. However, various other efforts have been made to produce models of rural road safety, using a range of techniques. Some of the more promising ones are presented below.

4.2.1 Interactive Highway Safety Design Model (IHSDM)

A major project of relevant interest here is the Interactive Highway Safety Design Model (IHSDM), being carried out by the US Federal Highways Agency (FHWA 2001). IHSDM will be a suite of evaluation tools for assessing the safety impacts of geometric design decisions. IHSDM's evaluation capabilities will help planners and designers maximize the safety benefits of highway projects within the constraints of cost, environmental and other considerations. The initial development efforts are restricted to two-lane rural highways, with work on multi-lane highways to follow.

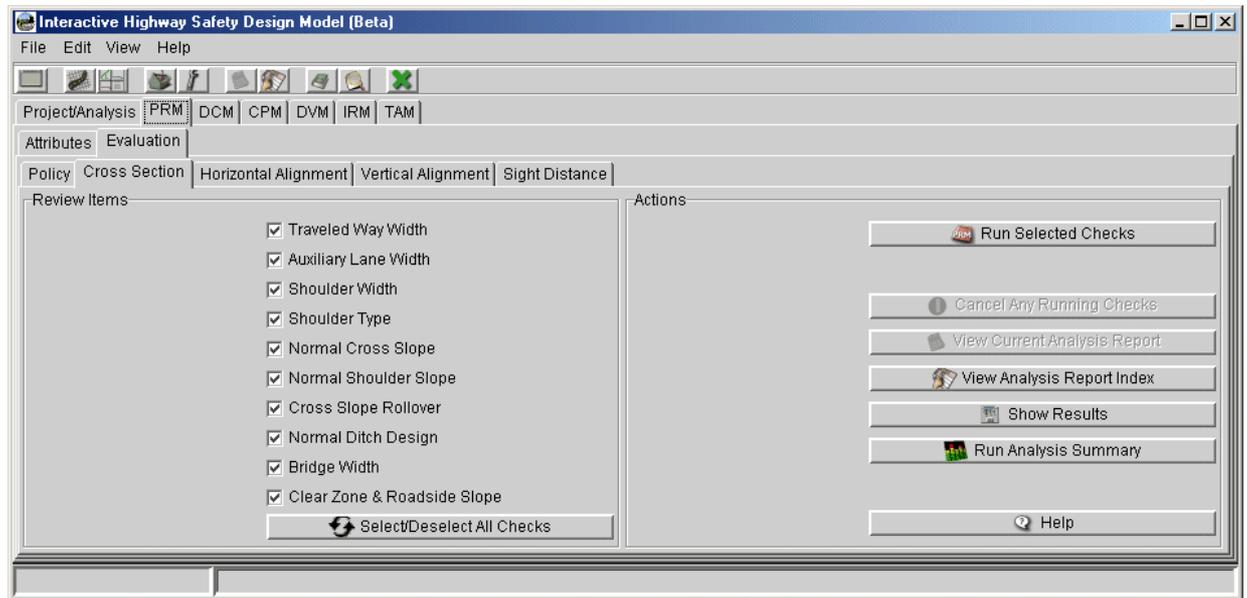
The full IHSDM package was not available in time for this review – final release was planned for the end of 2002. At the time of review, beta-testing of the various modules was underway and the author was able to obtain some of these modules for review; Figure 4.1 shows the appearance of the main program, with tabs for selecting the various program modules. Evaluation has also included background papers and research discussing the proposed modules, as well as correspondence with the US researchers.

Figure 4.1 IHSDM Main Program Window

IHSDM consists of several analysis modules:

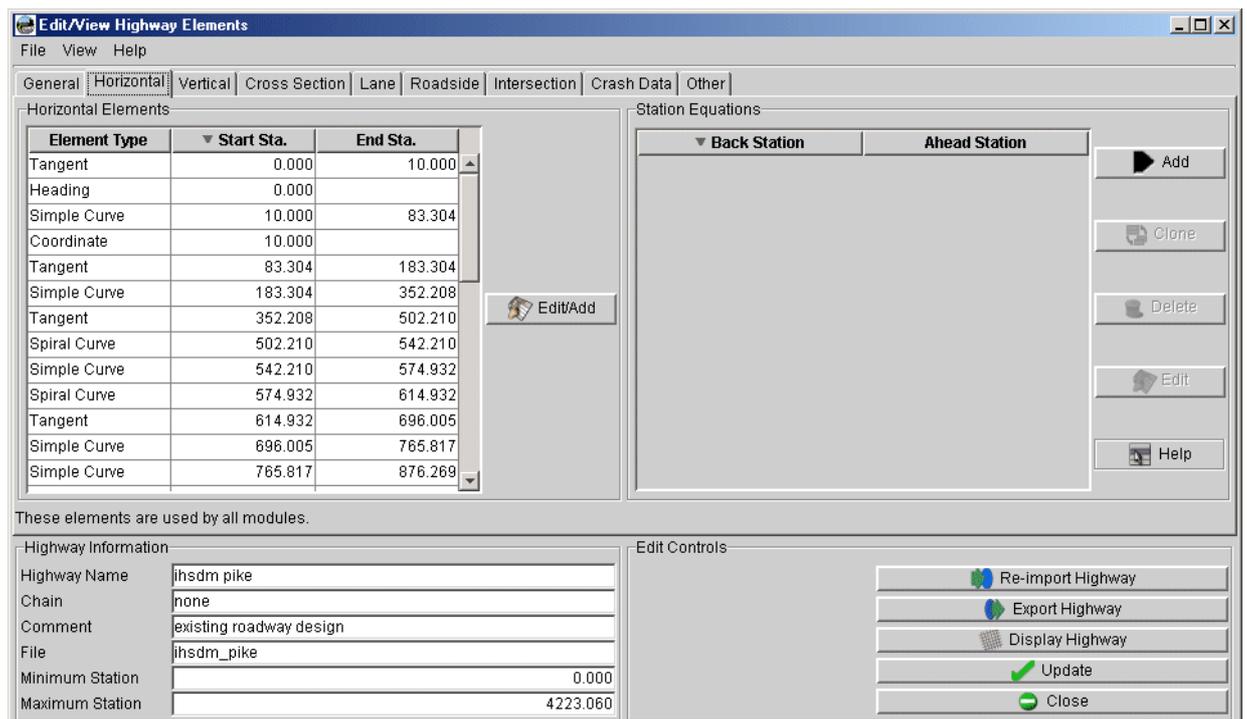
- Crash Prediction Module (CPM), to estimate the number and severity of crashes on specified roadway segments.
- Design Consistency Module (DCM), to provide information on the extent to which a roadway design conforms to drivers' expectations (especially speed profiles).
- Driver/Vehicle Module (DVM), consisting of a Driver Performance Model linked to a Vehicle Dynamics Model. These will estimate drivers' speed and path choice along a roadway and subsequent measures including lateral acceleration and friction demand.
- Intersection Diagnostic Review Module (IRM), which will use an expert system approach to evaluate intersection design alternatives, identify geometric elements that may impact on safety, and suggest countermeasures.
- Policy Review Module (PRM), to verify compliance with specified national/state highway design policies – see Figure 4.2 for an example of the items evaluated.
- Traffic Analysis Module (TAM), using traffic simulation models to estimate the operational effects of road designs under current and projected traffic flows, e.g. travel times, vehicle interactions. This is based on the TWOPAS model previously investigated.
- A Roadside Safety Module (RSM) is also being developed to evaluate the impacts of decisions such as the placement of guardrails, embankment slopes, continuous obstacles, and other hazards.

Figure 4.2 IHSDM Policy Review Module



These modules have been packaged together as a single application, together with associated support tools. For example, a major requirement of the program is the ability to explicitly specify in detail the design aspects of the highway proposal to be investigated. As well as a built-in highway editor (see Figure 4.3), FHWA have also been working to develop import tools for major CAD/design software packages (e.g. GEOPAK), and ultimately to allow for IHSDM modules to be integrated within these packages. With MX-ROADS by Infracore being the most favoured design tool in Australasia, development of functionality for this package in the near future would be of most use in New Zealand.

Figure 4.3 IHSDM Highway Editor

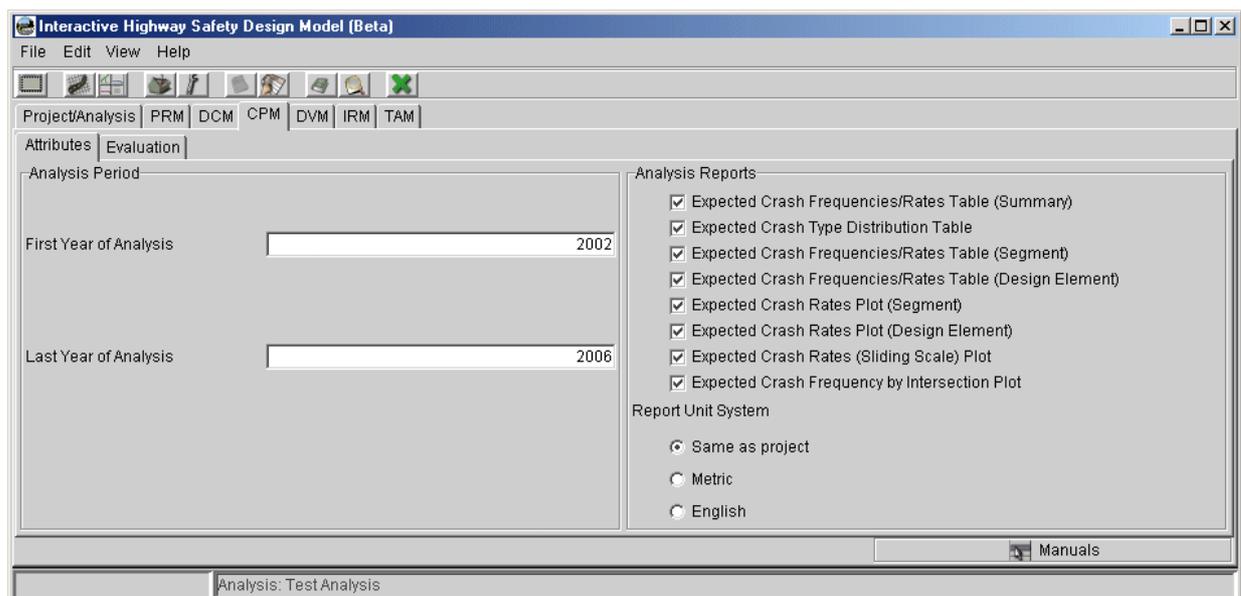


A considerable research effort has gone into the specification of the various modules. Although the finished modules may not be directly applicable to New Zealand conditions, the underlying research is still expected to be of significant value here. Therefore an investigation of the capabilities of IHSDM in a New Zealand context is warranted.

Harwood *et al* (2000) developed the crash prediction model used in IHSDM for predicting the safety performance of a rural two-lane highway. The crash prediction algorithm consists of base models and crash modification factors for both roadway segments and at-grade intersections. The base models provide an estimate of the safety performance of a roadway or intersection for a set of assumed nominal or base conditions. The crash modification factors adjust the base model predictions to account for the effects on safety for roadway segments of lane width, shoulder width, shoulder type, horizontal curves, grades, driveway density, two-way left-turn lanes (i.e. "flush medians"), passing lanes, roadside design and the effects on safety for at-grade intersections of skew angle, traffic control, exclusive left- and right-turn lanes, sight distance, and driveways.

The crash prediction algorithm is intended for application by highway agencies to estimate the safety performance of an existing or proposed roadway. The algorithm can be used to compare the anticipated safety performance of two or more geometric alternatives for a proposed highway improvement. A calibration procedure can also be used to adapt the predicted results to the safety conditions encountered by any particular highway agency on rural two-lane highways. The algorithm also includes an Empirical Bayes procedure that can be applied to utilize the safety predictions provided by the algorithm together with actual site-specific crash history data. Figure 4.4 shows some of the report options that can be selected by the module.

Figure 4.4 IHSDM Crash Prediction Module



Levison *et al* (2001) outlines the theoretical development being incorporated into the Driver Performance Model (DPM) of the DVM (not available for testing yet). The DPM has six major computational functions:

- Perception (identify sight distance limitations, distances/positions/speeds, allowance for errors)
- Speed Decision (use comfort and posted speeds to determine acceleration/deceleration)
- Path Decision (assume either curve cutting or follow lane for different drivers)
- Speed Control (time delay between pedals, pedal depression rate)
- Path Control (assume feedback loop to correct errors after action/perception delay)
- Attention (currently assumed to have full attention to driving)

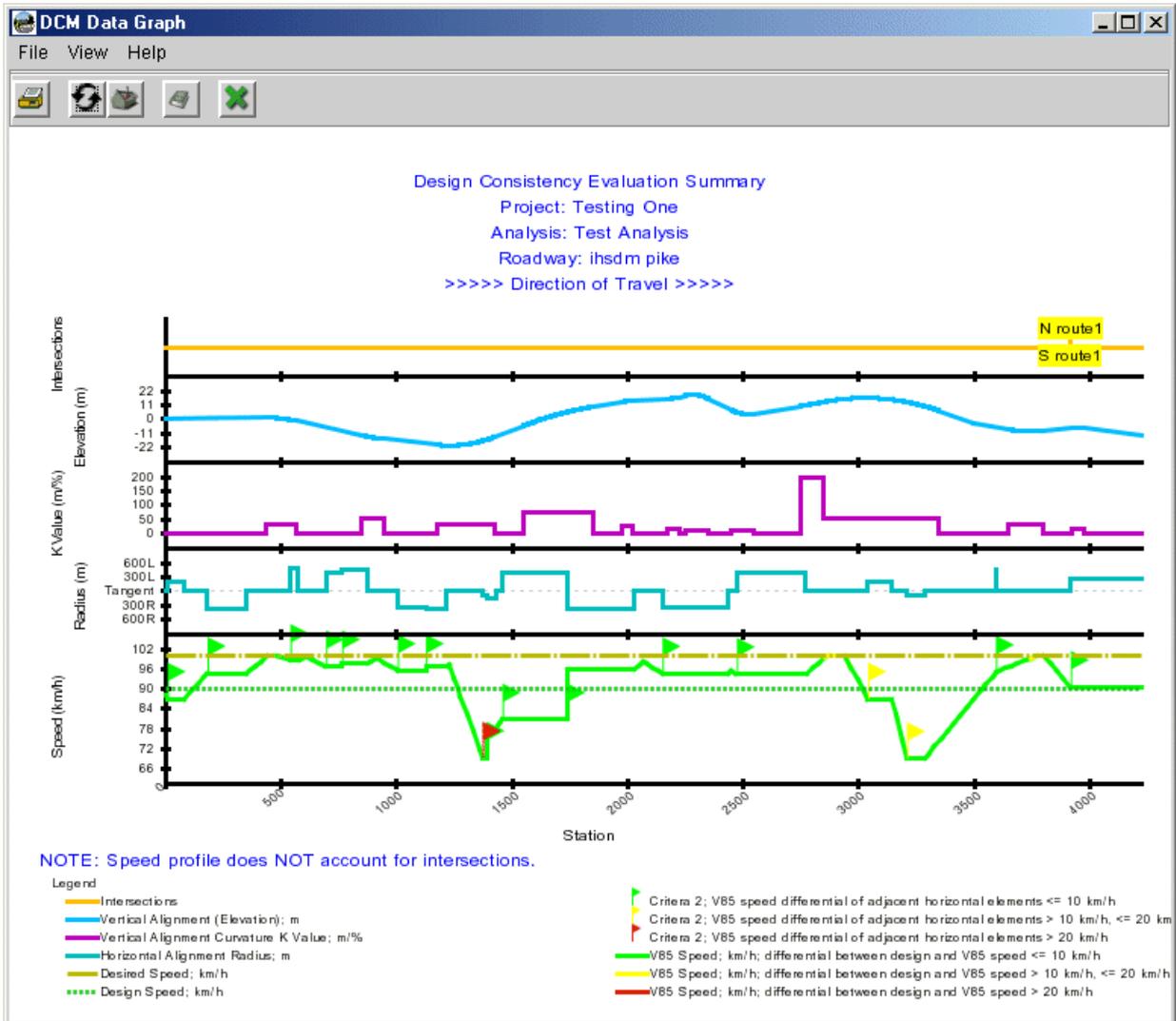
Some key assumptions used in the DPM to date are:

- The driver is experienced at the driving task in general (controls, steering, etc), but not necessarily familiar with the highway geometry presented.
- Drivers make appropriate decisions/actions, given good perceptual information.
- The driving environment is relatively relaxed (i.e. not emergency situations)
- Only vehicle path and speed tasks are considered. Other tasks such as monitoring traffic signs and other traffic are generally not included.

Although the above assumptions help to simplify the behavioural model required, it has to be accepted that exceptions to all of these assumptions (e.g. inexperienced drivers, distractions) are often significant factors in many crashes.

The results from IHSDM can be reported in a number of different formats. Various text-based reports can be produced and customised to suit. Graphical data can also be presented, as shown in the example in Figure 4.5. As well as charting road geometry data, this plot also shows a speed profile along the highway that is used by the DCM to identify inconsistencies in speed environment. The plotting layout is very similar to that commonly produced in New Zealand these days for state highway strategy studies.

Figure 4.5 IHSDM Design Consistency Module Results



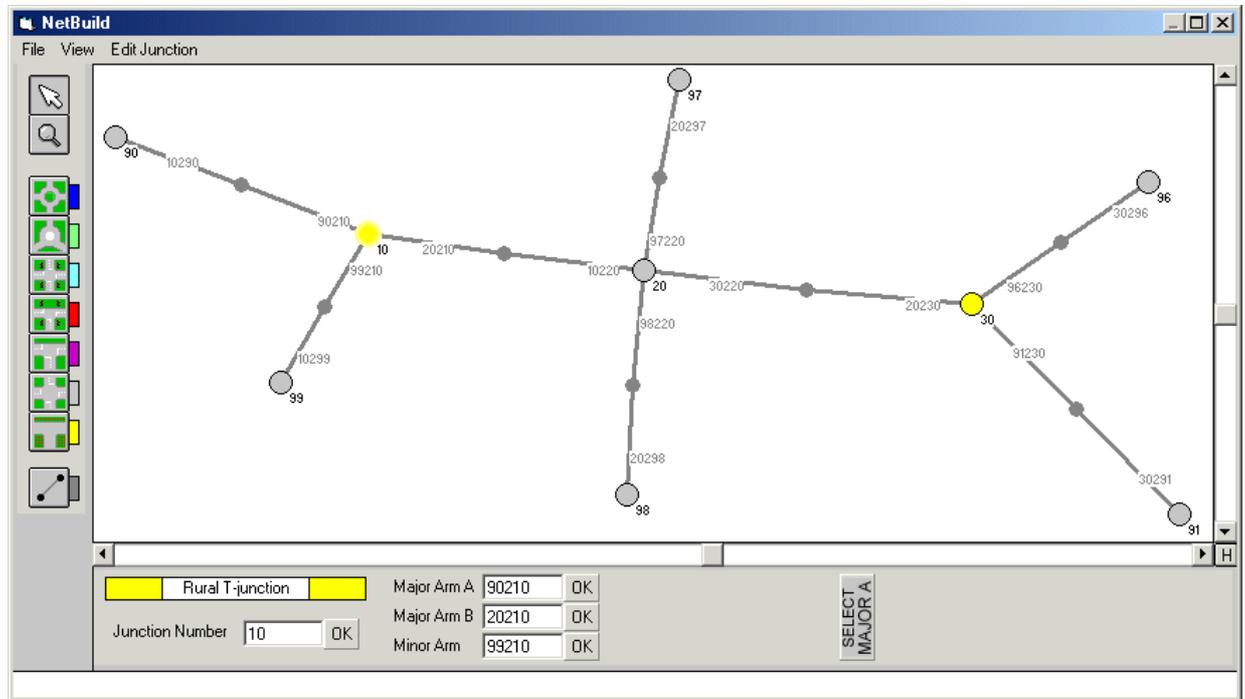
IHSDM is currently provided with US Federal (AASHTO) standards and guidelines on which to base its decisions about design consistency and policy compliance. These however are specified externally, and the program is designed to be able to accept alternative criteria such as state department or local design policies. Therefore, local guidelines such as those in Transit NZ's *State Highway Geometric Design Manual* (Transit NZ 2000) could be adopted for use with IHSDM fairly easily. Other parameters such as vehicle types modelled can also be modified relatively easily to reflect local traffic streams.

4.2.2 SafeNET

SafeNET (Software for Accident Frequency Estimation for Networks) is a new software package, developed in the UK by TRL, to assist traffic engineers in the design of safer road networks in towns and cities (TRL 2002). SafeNET provides a rapid assessment of the safety effects of potential network management changes, such as a change of intersection control or redistributed traffic volumes. Graphical and textual outputs enable the user to see how such changes affect the crash frequency on the network.

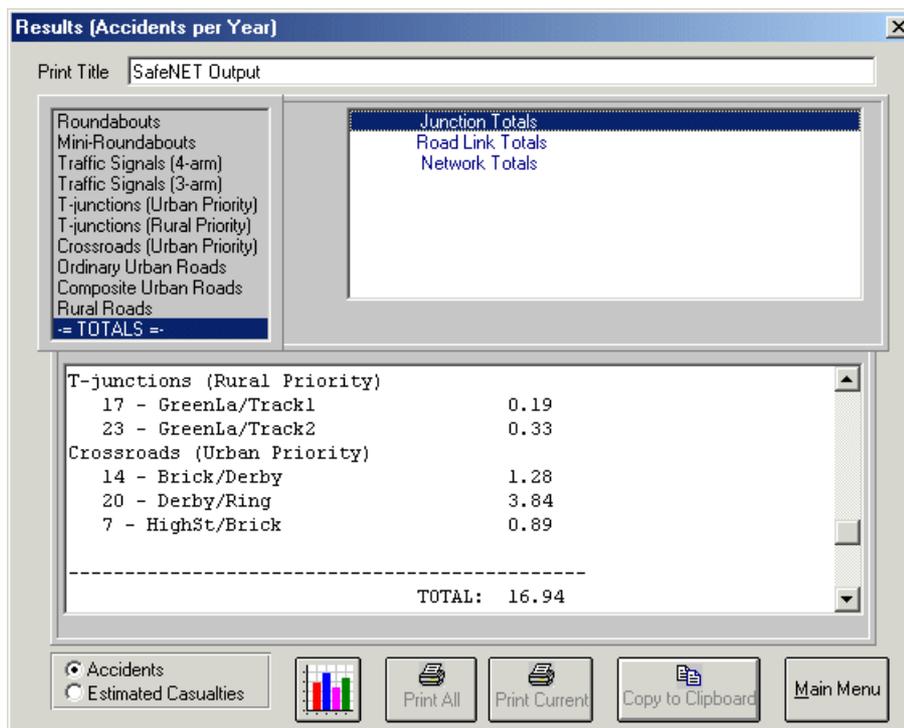
A network of road links and intersections can be graphically created within the program (see Figure 4.6), or data can be imported from certain traffic modelling packages. A range of road and intersection types can be chosen from, primarily in an urban context.

Figure 4.6 Network Editor in SAFENET



SafeNET implements a number of crash-risk models developed from different UK studies. These allow estimates to be made of the crash frequency (number of crashes per year) for particular elements of the road network (intersections of different types and road sections). SafeNET treats each intersection or road section individually. The total number of crashes predicted in the network is obtained as a sum of the estimates for each element. Figure 4.7 shows a typical report summarising the contribution of each road element.

Figure 4.7 Typical Summary Accident Predictions in SAFENET



Total intersection or road link crash frequencies are obtained by entering information on vehicle/pedestrian flow and simple site characteristics. By entering more specific geometric data, intersection turning flows and other design features, more detailed analysis can be carried out giving crashes by category, for example single-vehicle crashes, right-turning conflicts etc. As a result of allowing the effect of design features to be taken into account, SafeNET can be expected to give more accurate crash predictions. Figure 4.8 shows some of the attributes that can be specified when editing a road section.

Figure 4.8 Road Section Editor in SAFENET

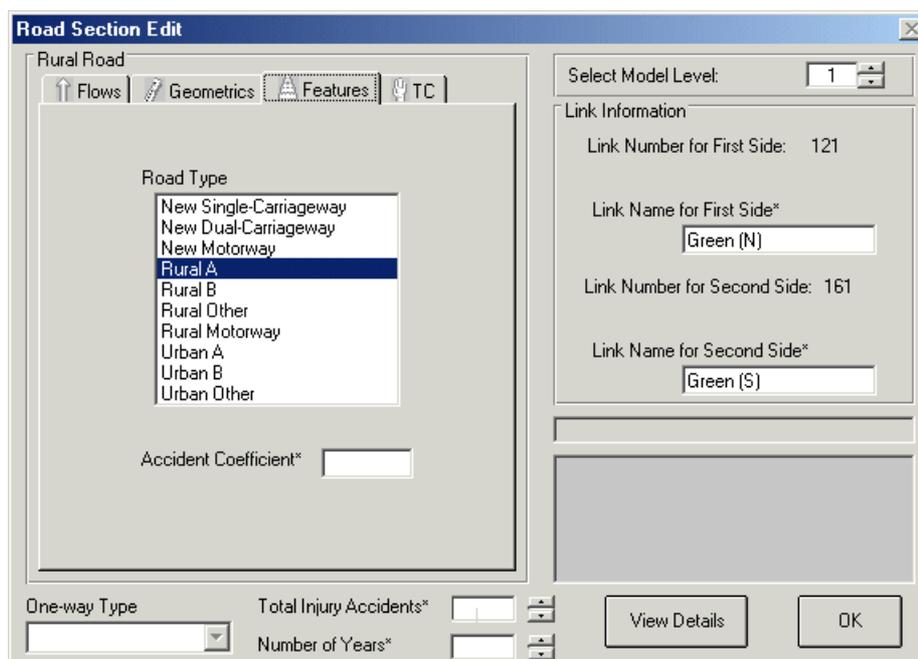
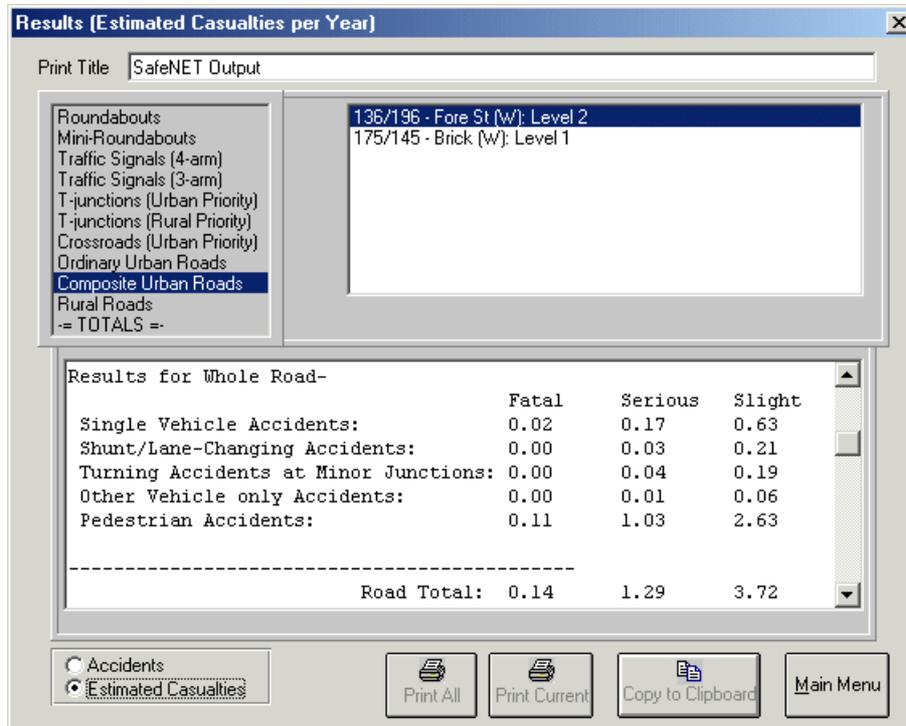


Figure 4.9 shows an example of the detailed estimates that can be produced from the more detailed crash models. This enables comparisons to be made of the effects of network changes on crash types and severities.

Figure 4.9 Typical Detailed Casualty Results for Road Section in SAFENET



Under normal circumstances, SafeNET will predict the crash frequency by only using the flow and geometric data entered. However, by entering values for the total (historical) injury crashes over a number of years, SafeNET can modify the prediction to take account of prevailing local conditions. The modification is made using the well-established Empirical Bayes technique, outlined by Hauer (1997). The longer the recorded observation period, the greater the weighting given to the observed value rather than the prediction. The intersection editing screen in Figure 4.10 shows fields available to enter existing crash data (right side).

Figure 4.10 Intersection Editor in SAFENET

Rural T-Junction

Junction Information

Junction Number: 17
 Model Level: 3
 Junction Name*: GreenLa/Track1
 Area or Group*: 2
 Number of Arms: 3
 Total Injury Accidents*:
 Number of Years*:

Arm Information

	Entry Link Number	Name*
Major Left	121	Green La (N)
Major Right	163	Green La (S)
Minor	151	Track 1 (W)
Arm D		
Arm E		
Arm F		

Buttons: Arm Data, Junction Data, OK

Although SafeNET is primarily designed for modelling urban road networks, with various forms of intersection control and traffic management features, it does allow rural road links and priority intersections to be included. However the level of detail, in terms of key geometric elements such as curvature and sight distances, is fairly limited. A similar approach to SafeNET more specifically focused on rural highways merits investigation however.

4.2.3 Road Safety Risk Manager

In 1998 AUSTRROADS commissioned ARRB Transport Research to develop a procedure to rank the recommendations derived from the road safety audit of existing roads; often the number of recommendations produced greatly exceeds the immediate implementation budget available. Based on the findings of this project, a risk management approach to prioritising road safety treatments was developed. A spreadsheet-based prototype was produced and provided to Australasian road authorities for trialling. Brodie & Koorey (2000) provided feedback from a New Zealand perspective. Responses from these trials were incorporated into the methodology and customised software was developed to form the present Road Safety Risk Manager program (McInerney 2001), shown in Figure 4.11. Further trials are currently underway on this software before general release.

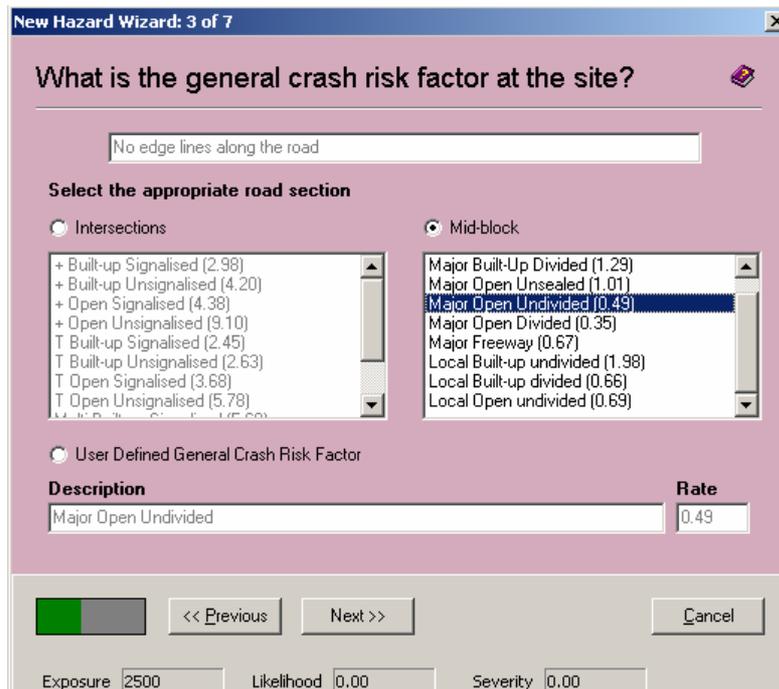
Figure 4.11 Main Menu Screen for Road Safety Risk Manager



The methodology is based on the measurement of risk as a function of exposure, likelihood and severity, and provides users with the ability to analyse the relative risk of a hazard and its proposed treatment. More than 50 different types of deficiencies have been quantified to date, across a variety of different road types and severity outcomes. Following inclusion of treatment costs, the derived "risk-cost ratio" (i.e. the reduction in relative risk per unit of cost) forms the basis of prioritising the proposed works. During initial testing it became evident that the process could be applied to all road safety treatments, not just those from existing road safety audits.

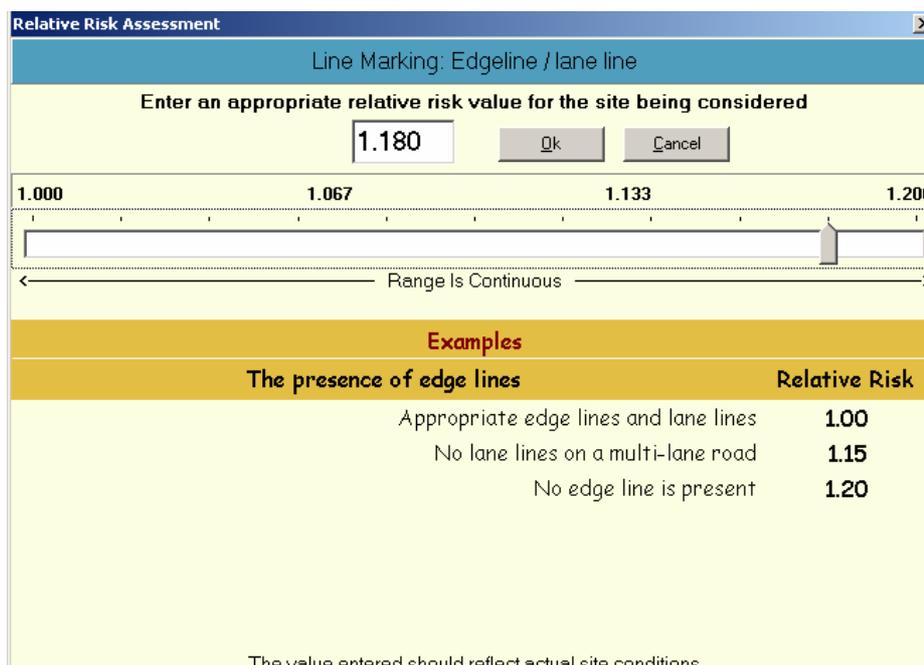
For different road and intersection types, general crash risk factors have been derived to differentiate the relative risk of each facility, all other things being equal (see Figure 4.12). The other key scaling factor is the traffic exposure, based on how much of the prevailing daily traffic volume could face the hazard being investigated (e.g. 50% of AADT for a hazard on one side of the road).

Figure 4.12 RSRM General Crash Risk Factor for different road types



The relative risks for each deficiency type are based on a literature review of many crash studies. A continuous range of treatments/standards is presented for the user to select the appropriate level of risk present (see Figure 4.13). The "best case" (safest) scenario is given a relative risk of 1.00, with lesser standards resulting in higher risk values. For example a feature with a relative risk of 1.20 is expected to have 20% more crashes than the safest case. The descriptions of standards are (by their nature) usually somewhat subjective, and so some engineering judgement is required to select a reasonable value. These risks are scaled by the general crash risk factors to allow for their effect on different facilities.

Figure 4.13 RSRM Relative Risk Factor for different road features



To set the relative risk in context, a number of influencing factors are provided (appropriate to each deficiency) that allow the base relative risk to be scaled according to the particular site in question. For example a roadside hazard on a narrow road with a winding alignment is likely to pose a greater risk than the same hazard on a wide straight road. Influencing factors can be changed in a similar way to the relative risk factors above, with 1.00 being the best case. Figure 4.14 shows how the influencing factors are weighted to affect the relative risk.

Figure 4.14 RSRM Influencing Factors that affect relative risk

The screenshot shows a software window titled "New Hazard Wizard: 5 of 7". The main heading is "What is the effect of other road factors at the site?". Below this, there is a text input field containing "No edge lines along the road".

Influencing Road Factor	Relative Risk	Weight	
1 Skid Resistance (surface): Mid-Block	1.09	0.20	Change
2 Lane Width	1.20	0.20	Change
3 Shoulder Width	1.26	0.20	Change
4 Horizontal Alignment (curve radius)	1.00	0.30	Change
5 Weather	1.29	0.10	Change
Relative risk influencing factors	1.14		

At the bottom of the window, there are navigation buttons: "<< Previous", "Next >>", and "Cancel". Below these buttons, there are three input fields: "Exposure" with value 2500, "Likelihood" with value 8.09, and "Severity" with value 0.00.

The other key effect on the hazard risk is the relative severity of the crashes caused. The user identifies the likely make-up of crash types and their relative severity is determined, based on the average social costs of each crash type (see Figure 4.15). Where a roadside ("clear zone") hazard is involved, the calculations are also based on the type of object and its distance away from the road.

Figure 4.15 RSRM Relative Severity for different safety problems

Determine severity of a crash if it does occur

No edge lines along the road

Step 1 Is the site in a built-up (lower speed) or open area (higher speed)?
 Built up area (< 80 km/h) Open area (>= 80 km/h)

Step 2 Select the crash types (and %) likely as a direct result of the hazard

Crash types	% (Σ 100%)	Off-Carriageway Adjustment	Relative Severity
Off carriageway - straight	75	0.80	3.14
Head On	15	1.00	5.23
Loss of control-straight-on carriagewa	10	1.00	1.70
	0	.	
	0	.	

Calculated severity value: 2.84

Exposure: 2500 Likelihood: 1.84 Severity: 0.00

The data for each hazard is combined to produce an overall Hazard Risk Score (see Figure 4.16). On its own, this number has no practical significance but it does enable comparisons with other hazards and with proposed treatments. In theory these risk scores provide a proxy for the expected social costs of crashes associated with the site, although comparing them with true crash rates and costs does not appear to be straightforward.

Figure 4.16 RSRM Overall Hazard Risk Score for safety problem

Summary of input

Exposure: 2500
 Likelihood: 1.84
 Severity: 2.84

Hazard Risk Score: 13083

Exposure: 2500 Likelihood: 1.84 Severity: 2.84

A similar process is undertaken for any proposed treatments to the hazard, producing an alternative Hazard Risk Score. By providing information on the cost of implementing the treatment, a Risk Cost Ratio for each treatment can then be calculated (see Figure 4.17). These can then be compared against each other, in a similar way to how Benefit-Cost Ratios are compared for projects here. Various reports and exporting options are available for summarising and analysing the results.

Figure 4.17 RSRM Risk Cost Ratio for proposed treatment of safety problem

Edit Treatment Wizard: 8 of 8

Estimate treatment life and cost

What is the hazard: No edge lines along the road
 Description of the hazard: Between Penwortham and Sevenhill
 Recommended Treatment: Install high quality edge lines
 Hazard Risk Score: 13083 Treatment Risk Score: 11088

What is the life of the treatment? 3 years
 What is the initial outlay/cost? \$ 4800
 What are the ongoing costs? \$ 0
 What is the salvage value? \$ 0
 Discount Rate (7% standard) 7.0 %

Discounted Risk Reduction: 5237
 Discounted Costs \$: 4800

Risk Cost Ratio 1.09

<< Previous Finish Cancel

Exposure 2500 Likelihood 1.56 Severity 2.84

Although further work is continuing to improve the risk factors used and improve the methodology, the existing program provides a considerable advance to previously subjective means of prioritising road safety projects. While the model is primarily targeted at Australian road safety practitioners, work is continuing to provide suitable New Zealand values for various parameters to allow its application here. For example, relative severity costs are greater for fatal crashes in New Zealand, compared with Australia.

4.2.4 Other Safety Models

Hunt & Mahdi (1995) describes the development and assessment of a model for predicting crash frequency on rural single carriageway roads. A database describing the crash frequency, layout, geometric design and traffic characteristics of 500 0.5 km sections of single carriageway road was assembled, with a micro-simulation model, OSCA, used to generate many of the traffic parameters. Existing data included factors such as AADT, "bendiness" and the number of side road accesses, while traffic data such as mean spot speed and percentage of impeded vehicles was generated at 50m intervals. A multiple linear regression model for crash frequency was found to provide the best fit to the data (as opposed to a multiplicative model), although the fit was still relatively poor for sites with high/low crash frequencies.

The most significant factor was the difference between the 50 m interval mean speed and the overall mean speed of a road section, similar to the measures of local speed versus speed environment mentioned previously. The model could be applied to evaluate variations in crash frequency that would be associated with changes in layout, geometric design, or traffic flow on rural single carriageway roads.

In Europe, the SAFESTAR (Safety standards for road design and redesign) project is a research study focusing on traffic safety for what is known as the “Trans-European Roadway Network” (TERN) that links the major European centres. The aim is to develop safety standards for highway design and redesign on all classes of road involved (Wegman & Slop, 1995). Nine European research institutes are collaborating on SAFESTAR, with the (Dutch) SWOV Institute for Road Safety Research coordinating these activities. Of the eight priority areas being investigated, two of particular relevance are “cross-sections of rural roads” and “design of curves in rural roads”, and working papers have been produced documenting the findings to date (Cardoso *et al* 1997, VTT 1999). Although the project does not include the specific development of road safety models, the literature review has identified a large number of models developed in the past from which to produce best practice guidelines. Some of these could be revisited for development of local models.

The Swedish Centre for Traffic Simulation Research (CTR) is working to develop indicators for safety in urban intersections using micro-simulation (SINDI project, Archer 2000). Crashes and conflicts occur as a consequence of individual and temporal variations in driver behaviour, errors in perceptions, errors and delays in decisions and errors in performance. In order to assess safety one must introduce such variances in behaviour, so such a behavioural model has been used by CTR, based on a further development of the Finnish HUTSIM traffic simulation model. CTR plan to extend the SINDI project into safety assessment for rural roads, however this will not be available in time for this review (Andréasson 2001).

The Finnish National Road Administration (FinnRA) evaluates yearly traffic safety improvement targets using a program called TARVA (named for the Finnish words which mean "Evaluation of Safety Effects Using Effect Coefficients"). Introduced in 1995, TARVA uses crash models together with crash history to estimate the expected number of crashes on the road if no measures were to be implemented. The effects of measures can then be evaluated using a standard set of incidence and severity reduction factors for different treatments. Relatively simple models, largely based on vehicle exposure, are primarily used to estimate average risk for homogenous road sections, with more complex models available if necessary that include sight distances, road widths, etc. FinnRA found that, when combined with historical crash data, more complicated models did not significantly improve the prediction effects (Peltola 2000). It may be possible to adopt or incorporate a system like this into a rural road safety model here.

4.3 Applications for New Zealand

4.3.1 Existing Crash Reduction Evaluation in New Zealand

Project evaluation of safety benefits is currently prescribed by procedures in Transfund New Zealand's *Project Evaluation Manual (PEM)* (Transfund 2001). Crash benefits are either determined by applying estimated reductions to existing crash rates ("accident-by-accident analysis") or by assigning typical crash rates to new or changed facilities ("accident rate analysis"). For rural highways, typical crash rates are provided for broad terrain and volume categories, as well as predicted crash savings from treatments such as passing lanes and resurfacing. Differences in crash rates on isolated curves are also provided, based on the approach and minimum curve speeds, and similar crash differences are provided for different cross-section attributes (e.g. wider shoulders, flatter slopes). The information however provides little specific guidance on how combined changes in alignment and cross-section might be dealt with, such as with a realignment project. Generally there is limited advice on the proportion of different crash types involved and the relative changes to each type. In some cases, the provided data is also based either on overseas data not calibrated here or on outdated local crash research.

Turner (2001) re-analysed local crash data and produced a range of new prediction models for various intersection and mid-block situations. Although much of the work was focused on urban areas, mid-block and T-junction crash rates were also derived for rural (80-100 km/h) highways. These provided a breakdown of predicted crash numbers by different types (e.g. rear-end, overtaking, etc), although this relies on having known turning volumes to split intersection crash numbers like this. The mid-block rates are only provided for generic "level" and "rolling" terrains, with two-way daily traffic volume being the only input parameter (somewhat counter-intuitively, the crash rates for rolling terrain were lower overall than those for level terrain). There is therefore scope for incorporating other geometric or environmental features into a model for more detailed estimation.

Currently the PEM only allows the option of using either historical crash data or, where this is inappropriate or unavailable, typical crash rates. However there are plans to allow the option of combining these sources of information (Turner 2002), using a form of Empirical Bayes technique. This should provide for a more accurate assessment of safety benefits, although it needs to be repeated that the crash models for rural highway mid-block sections are still fairly undeveloped with regard to road geometry.

One means of obtaining additional crash reduction information is via LTSA's Crash Reduction Monitoring (CRM) Programme (LTSA 2001c). Set up in 1985, this programme identifies sites where there are similar crash patterns and recommends low cost engineering treatments aimed at reducing those crashes. Sites where road safety works have been carried out (perhaps following a crash investigation study) are monitored for changes in crash numbers and overall findings reported on a fairly regular basis. Typical rural treatments that have been reported on to date include installing chevron arrows at bends and shoulder improvements.

There are two key problems with the CRM results at present. Firstly, where sites are selected for treatment on the basis of high crash counts, there is likely to be some reduction in crashes in subsequent years even if no works were carried out, otherwise known as "regression to the mean". LTSA acknowledge this problem, but no adjustment to the published results has been determined yet. However the effect could be relatively minimal if long before/after analysis periods have been used, such as five years. Secondly, in many cases, a number of other treatments are carried out at the sites at the same time (e.g. upgrading signs *and* improving lighting), making it difficult to distinguish the specific benefits of each treatment. This could lead to an overstatement of the benefits attributable to a particular treatment. Conversely it could also lead to an understatement of benefits if the treatments are not supportive of each other. Nonetheless, the programme represents a dataset that is hard to match around the world.

4.3.2 Crash Type Incidence on New Zealand Rural Highways

It is pertinent to consider the relative proportion of crashes actually occurring on New Zealand highways, so that attention can be focused in the right areas. It would be overzealous, for example, to concentrate on an accurate prediction model for certain types of crashes if they actually made up less than 1% of the total reported numbers.

Table 4.1 summarises the numbers of reported injury crashes on rural (100 km/h) State Highways between 1996-2000. Only State Highway data have been used, on the basis that this type of road represents those typically warranting modelling and realignment or other such treatments. However, other rural roads are likely to have similar crash characteristics. Data for two-, three- and four-lane highways are presented, although it is difficult to separate four-lane motorways and expressways from undivided highways. Crash numbers for two-lane highways clearly dominate, reflecting their prevalence in New Zealand.

Table 4.1 Crash Type Numbers on NZ Rural State Highways 1996-2000

Crash Types	Number of Lanes			ALL
	2	3	4	
Curved Rd - Head On / Lost Ctrl	3773	256	28	4057
Straight Rd - Head On / Lost Ctrl	1611	157	51	1819
Rear-end / Obstruction	854	244	77	1175
Intersection	700	137	58	895
Overtaking	592	138	28	758
Pedestrian/Misc	234	24	4	262
TOTAL	7764	956	246	8966

For two-lane highways, head-on/lost-control crashes on curves comprise almost half (49%) of all reported crashes, with similar crashes on straights contributing the next highest proportion (21%). Rear-end/obstruction crashes play a greater role on three and four-lane highways (31% of the latter), probably reflecting the increasing levels of congestion and traffic interaction. Intersection and overtaking-related crashes make up still smaller proportions, although intersection crashes are relatively common on four-lane highways (24%). Pedestrian and other miscellaneous crash

types occur less than 3% of the time, largely due to the absence of their contributing features on rural highways (e.g. pedestrians crossing, parking).

Given that the top five categories contribute at least 8% each to crashes on rural highways, they should ultimately all be considered for safety modelling. The relative priorities will need to consider the actual proportion of, and hence exposure to, different road environments (e.g. straight versus curved roads), as well as the existing availability of research on each crash type. Clearly however, on sheer numbers alone, development of crash prediction measures for head-on/lost-control crashes on curves is the first priority. While some crash prediction information is available in the PEM for isolated curves, this needs to be considered further in the context of combinations of curves, as well as investigating the effect of other relevant parameters. As more four-laning becomes common, development of accurate measures for the other crash types will become equally important.

Another relevant statistic is that 54% of the crashes on two-lane highways involved only one vehicle – and given the lower reporting rate for single-vehicle crashes, the true proportion is probably higher. The finding is reflected in the prevalence of lost-control crashes in the data. This has implications on how road safety models might be developed; a "traditional" traffic conflicts model for example will clearly have only limited use. For three and four-lane highways the proportions of single-vehicle crashes are lower (33% and 21% respectively), reflecting the increased traffic interaction likely to be present.

An analysis of cause codes may help to identify key unsafe driving actions in New Zealand, as described above by Charlesworth & Cairney (1988). The top factors identified in the above crashes (excluding alcohol) are listed in Table 4.2, with those identified more than 5% of the time for a particular crash type shown in **bold**.

Table 4.2 Top Cause Codes in Crashes on NZ Rural State Highways 1996-2000

Cause Code (note: alcohol-related causes not specifically listed)	Percentage of Crashes Affected in Stated Category					
	All Crashes	Curve – Head-On / Lost Ctrl	Straight – Head-On / Lost Ctrl	Rear-end / Obstruct'n	Intersect'n	O'taking
Too fast entering corner	10.2%	21.5%	0.5%	1.3%	0.2%	1.3%
Fatigue (drowsy, tired, fell asleep)	4.2%	3.9%	11.6%	0.7%	-	0.4%
Lost control while returning to seal from unsealed shoulder	4.1%	5.5%	6.2%	0.3%	0.1%	4.2%
Didn't check behind when changing lanes position or dir'n	3.0%	-	0.1%	11.7%	6.0%	10.3%
Following too closely	3.0%	0.1%	0.5%	20.1%	0.4%	1.8%
Inattentive: failed to notice	2.6%	1.5%	2.1%	7.7%	2.5%	1.5%
Failed to give way at give way sign	2.5%	0.1%	0.1%	-	24.4%	-
Lost control when turning	2.4%	5.2%	0.1%	-	-	-
Failed to give way when turning to non-turning traffic	2.3%	-	0.1%	0.2%	22.6%	0.3%
Swung wide on bend	2.0%	4.4%	-	-	0.1%	-
OTHER CAUSES	63.7%	57.8%	78.7%	58.0%	43.7%	80.2%

More detailed analysis can be made within each crash type to identify the main causes, e.g. the top factor identified in overtaking crashes was "overtaking deliberately in the face of oncoming traffic" (10.8%), although it was reported in only 1.0% of all crashes. The above figures also have to be viewed with some reservations, given the vagaries in reporting by the attending traffic officer at different crash types, and the often-limited evidence apparent from both the site and the vehicle occupants. It is also pertinent to note the high proportion of crashes that have causes *other* than these top ones attributed to them (or none at all). However it will suffice for identifying a list of UDAs for further investigation.

4.4 Assessment of Road Safety Models

The road safety models featured above display a wide variety of techniques and make use of differing sets of data, indicating the complexity of the task of accurately estimating safety effects. Some general observations can be inferred:

- Overseas models would probably require some adjustment to their parameters to give suitable estimates in New Zealand. Few appear to allow for this calibration by users, with IHSDM being a notable exception. However the developers of the Road Safety Risk Manager are endeavouring to specify suitable alternative values for use in both Australia and New Zealand.
- Driving speed, and its relationship to the surrounding speed environment in particular, is a significant factor in assessing the relative safety of locations. Speed factors also show up as a major cause of crashes in New Zealand. An accurate means of predicting vehicle speeds is therefore necessary.
- Traffic or driving conflict models may have some limited applications for predicting certain types of rural crashes, but they are still relatively difficult to develop and validate, particularly where the measured conflicts are fairly rare (e.g. non-intersection measures).
- Inclusion of actual historical crash data should greatly help to adjust crash predictions for local effects that are otherwise difficult to account for. This allows a relatively simple but effective model to be developed and used fairly quickly, ahead of further research into other factors.
- New Zealand is luckier than many countries in having a fairly integrated system for collating relevant highway data (e.g. traffic volumes, crashes, road geometry, skid resistance), particularly on State Highways. This advantage should be maximised in both developing and using any crash models here.
- The scope of the model will dictate the data used. For example, a nationwide strategic highway crash model here in New Zealand could make use of the relevant data already available in highway databases. For more site-specific models however, some detailed on-site data collection may be required, e.g. to assess roadside hazards and to determine sight distance constraints.
- A road safety model based on measurable engineering attributes would probably still benefit from setting these measures in a driver behaviour context, particularly given that it is often a combination of atypical road features and atypical driver behaviour that cause crashes.

None of the overseas models examined could be immediately used here for absolute crash prediction (e.g. typical crash rates), given the relative differences in the roading, social and legislative environments. However in many cases, the models could perhaps provide a reasonable estimate of the *relative* change in crash risks between two situations, enabling practitioners to apply this relativity to the existing crash numbers. Even this assumption however has to be tested in the New Zealand context before applying the models unchanged.

Of all the models, IHSDM provides the greatest scope for local customisation, such as making use of New Zealand design policies and incorporating available road geometry data. The complexity and detail of this model however means that such customisation will require considerable effort. This level of effort will also be required when specifying roading alignment details for project evaluations, as IHSDM typically doesn't allow just a simple set of alignment information to be entered.

4.4.1 Potential Key Indicators of Relative Safety

The literature and model review identified a number of parameters that could influence the relative safety of a location. Further work may be justified in trying to relate these to actual crash numbers here. In many cases, they may only affect a certain subset of crashes, therefore requiring a range of measures to cover the whole spectrum of crashes. Some potential indicators identified include:

- Mean or 85th percentile travel speed (severity of resulting crashes)
- Available sight distance vs safe stopping/manoeuvring sight distance
- Required curve speed reduction from previous travelling speed
- Relative vehicle position in lanes (cutting corners, swinging wide, etc)
- Number of aborted or "close" overtaking manoeuvres (conflicts/avoidance by nearby vehicles)
- Number of "close" intersection manoeuvres (based on "time to collision")
- Number of vehicle "interactions" (e.g. oncoming vehicles, catch-ups)

It is worth carrying out some statistical analysis of the relative correlation between these factors and crash numbers. However, care must be taken not to automatically infer a cause-and-effect from an apparent correlation; a related measure may provide a better reason for the indicated relationship.

4.4.2 Development of Local Road Safety Models

The question remains whether there is merit in developing local road safety models further. The existing rural crash evaluation procedures in this country show distinct limitations in both the underlying theory and their practical application on more complex projects. As road safety becomes more advanced in New Zealand, and many of the "easy fixes" (e.g. black spots) have been implemented, more sophisticated models may be required to identify the often minor effects of changing small aspects of roading design. This will allow incremental improvements to the

relative safety of rural roads to be better identified and incorporated into future works.

A primary focus on curve-related crashes would cover by far the most important area of rural road safety in New Zealand. Other crash types could initially be predicted using simpler methods, such as those developed by Turner (2001), with more specific development of these later. Combining existing crash data in an Empirical Bayes methodology would also speed up practical application, although software tools may be required to encourage roading practitioners to make use of it..

The ability to integrate or link a rural road safety model to existing road design packages would be of immense practical value, enabling faster specification of road layouts for assessment and subsequent reporting and rework. Certainly, this is the ultimate aim of the IHSDM programme. Many of these packages already have the ability to estimate construction costs from a specified design; the calculation also of traditional road user benefits like crash reductions, travel-time savings and vehicle operating costs would provide a total package for determining cost-effective options. In this way designers could produce an optimal alignment that balances construction cost against reasonable safety and operating costs. This could be both at the strategic level (e.g. a route construction cost optimisation package like Australia's Quantm) and at the detailed design level (e.g. CAD design packages like InfraSoft's MX-ROADS, Bentley's GEOPAK & InRoads, or CAiCE's Visual Design).

That issue is, however, probably for future consideration. The first priority would be to scope the required needs for local road safety models at various levels, i.e:

- At the national/regional strategic level, to identify sections of hazardous or sub-standard highway
- At the project scoping level, to assess the relative merits of different options
- At the project design level, to determine the precise benefits of the proposed design
- At the highway audit level to identify and prioritise existing deficiencies

Each of these applications will require a different level of data collection (largely dictated by the cost-effectiveness of obtaining additional data) and a different level of output precision (determined somewhat by the need for absolute or relative safety measures). Therefore it may be likely that separate models will be required for each application, or that a particular subset of a model may be needed for some less specific applications.

5. Conclusions

This research has identified a number of potential rural road simulation packages and other relevant models for use in New Zealand to evaluate traffic efficiency and safety of different roading options. Further investigation is required to trial them and confirm their appropriateness.

5.1 Study Scoping and Site Selection

A review of local and international literature on relevant topics revealed:

- Horizontal and vertical alignments have the greatest influences on driver speed selection and therefore need to be modelled with some precision. Horizontal curvature and uphill grades are the key determinants, although the surrounding speed environment and sight distances may have an effect.
- Estimation of undesired vehicle-following and congestion delays is another important use of modelling. Key factors that affect the supply and demand for passing include traffic volume and composition, available passing sight distance, and traffic speed distributions.
- Predicting speed changes due to roadside development and lower speed limits is particularly difficult, and site-specific measurements are recommended. Such locations may affect high-percentile speeds more than the mean speed.
- Narrow road widths do not appear to have as much influence on vehicle operations as other factors, particularly for modelling on State Highways, which generally have adequate lane widths. Isolated clearance constraints such as narrow bridges may inhibit overtaking or speeding however.
- Other features that can affect modelling of highway traffic, both in terms of delays and safety problems, include side roads, one-lane bridges, and roadworks with traffic control.
- Most simulation models developed to date have been designed specifically for evaluation of efficiency issues (e.g. travel time savings and reductions in time spent following) rather than assessment of safety benefits. Analysis of both within the same package would be preferable for project development purposes.
- At present, most detailed rural simulation in New Zealand is carried out using TRARR (ARRB Transport Research, Australia). However, a number of existing concerns and limitations have been identified through practical experience, and no further upgrading is planned by the developers.
- TWOPAS 98 (FHWA, US) is a similar alternative tool that appears worth investigating. Current ongoing development makes it an attractive long-term proposition, although its appropriateness and practicality for New Zealand use needs to be confirmed.
- Network micro-simulation packages like PARAMICS 2001 (SIAS, Scotland), commonly used for urban and motorway modelling, may have the potential for rural simulation also. The appropriateness of the underlying driver behaviour models on typical New Zealand rural highways needs to be confirmed however.

- A desirable rural road model for New Zealand project evaluation should be able to take in a wide range of road, environment, traffic, vehicle and driver attributes and accurately predict measures of vehicle speed, running costs, crash risk, vehicle emissions, and driver comfort.
- As well as having the underlying theory sufficiently correct, a practical model should ideally allow for a number of other features to make it efficient to use. These include an intuitive graphical interface, easy creation and editing of input data, the ability to incorporate field data, customisation of outputs for uses such as project evaluation, and adequate documentation.
- Incorporation of road-modelling features into existing road design packages, such as MX-ROAD (Infrasoft, UK) could enable built-in assessment of designs in terms of road user benefits and costs, resulting in more immediate feedback on the most optimal designs.

From these findings, a survey plan (sites, methodologies) was developed to collect suitable field data for assessment of the various simulation models.

5.2 Field Data Collection and Simulation

Following field surveys at various rural highway locations, subsequent analysis and modelling showed:

- While some project types are well served by modelling tools (e.g. passing lanes), others are still not well supported (or at least for New Zealand situations). There may be scope for further research to develop suitable analysis tools for the industry.
- Each of the three main models investigated appears to have particular strengths over the others when considering different project applications. This suggests that, in the short-term at least, all three have a part to play in New Zealand rural modelling.
- TRARR still has a significant advantage in terms of familiarity to many New Zealand practitioners, and well-established support tools to enhance its use for project evaluation.
- TWOPAS generally has features at least as comprehensive as TRARR in terms of modelling various rural features. However it suffers at the moment from a limited means of bringing in road alignment data automatically. The next version of TWOPAS (currently in beta version) offers more promise.
- PARAMICS provides considerable flexibility to model situations not traditionally provided for by rural simulation models. This flexibility also means however that it is more difficult to quickly set up and run a model and obtain the required outputs. There is also still some question about the theory underlying the model's operation as it applies to rural New Zealand roads, even with appropriate calibration and validation.
- There are existing usability problems with both TWOPAS and PARAMICS that need to be addressed in future versions to make them more practical for rural highway use in New Zealand. In particular, a sporadic "stalled vehicle" error in PARAMICS needs to be urgently dealt with.

From this assessment, an initial ranking of suitability for different project types was produced.

5.3 Review of IHSDM and Related Safety Models

A review of local and international rural crash risk modelling revealed the following:

- Most existing crash analysis procedures are "static" models, i.e. they predict crash numbers by combining typical crash rates for a certain facility, traffic volumes, and sometimes additional site-specific modifying factors.
- Micro-simulation could be used to analyse driver/vehicle behaviour and identify what situations put road users at more risk than others. Rather than actually simulating vehicles crashing, observations of certain traffic "conflict" events could be used to assess likely crash rates. The application of this approach to mid-block situations is still relatively untapped, particularly where the measured conflicts are fairly rare (e.g. non-intersection measures).
- On rural routes, road features (e.g. curvature, roadside hazards, sight distance) are more important in determining both the likelihood and severity of crashes, whereas in an urban environment drivers are usually more constrained by either speed limits or other road users.
- Research on geometric features and crashes has found increasing crash risks significantly related to increases in horizontal curvature and absolute gradient as well as reductions in available sight distance.
- Higher mean speeds and speed variances increase crash rates and severities. Crash rates also increase as vehicle speeds fall significantly below the surrounding speed environment. An accurate means of predicting vehicle speeds is therefore necessary.
- IHSDM, or Interactive Highway Safety Design Model (FHWA, US), is a suite of evaluation tools for assessing the safety impacts of geometric design decisions on two-lane rural highways. The use of IHSDM in New Zealand, making use of local design standards, is a promising approach although considerable road design data is required for input.
- Many other potentially relevant road safety models have recently been developed internationally. These include SafeNET (TRL, UK), Road Safety Risk Manager (ARRB Transport Research, Australia) and TARVA (FinnRA, Finland). Many would probably require some adjustment to their parameters to give suitable estimates in New Zealand, although few appear to allow for this calibration by users.
- None of the overseas road safety models examined could be immediately used here for absolute crash prediction, given the relative differences in the roading, social and legislative environments. However in many cases the models could provide a reasonable estimate of the *relative* change in crashes between two situations.

- Inclusion of actual historical crash data should greatly help adjust crash predictions for local effects that are otherwise difficult to account for. This would allow a relatively simple but effective model to be developed and used fairly quickly, ahead of further research into other factors.
- For safety evaluation of rural highways in New Zealand, typical crash rates are available for broad terrain/volume categories, as well as predicted crash rate changes for specific treatments (e.g. passing lanes, resurfacing), curve speeds, and different cross-section attributes. However there is little specific guidance on how combined changes in alignment and cross-section might be dealt with (e.g. for realignments) and there is little knowledge of the effect on different crash types.
- New Zealand has a relatively well integrated system for collating relevant highway data (e.g. traffic volumes, crashes, road geometry, skid resistance), particularly on State Highways. The LTSA's Crash Reduction Monitoring Programme also provides a valuable source of data on the effectiveness of various road safety treatments. These advantages should be maximised in both developing and using any crash models here. For more effective site-specific models however, some detailed on-site data collection may also be required.
- For two-lane rural highways in New Zealand, head-on/lost-control crashes on curves comprise almost half (49%) of all reported crashes, with similar crashes on straights contributing the next highest proportion (21%). Less common are rear-end/obstruction (11%), intersection (9%) and overtaking-related (8%) crashes, although they play a much greater role on three and four-lane highways.
- A road safety model based on measurable engineering attributes would probably still benefit from setting these measures in a driver behaviour context, particularly given that it is often a combination of atypical road features and atypical driver behaviour that causes crashes.
- The existing rural crash evaluation procedures in New Zealand show distinct limitations in both the underlying theory and their practical application on more complex projects. As more of the "easy fixes" are implemented, more sophisticated models may be required to identify the often minor effects of changing small aspects of roading design for incremental safety improvements.

6. Recommendations

The following items are recommended for further investigation or action:

- Undertake further examination of the potential for incorporating safety assessment into future development of existing "travel efficiency" simulation models.
- Undertake further surveys of the type described in the survey plan to further validate the accuracy of the various simulation tools. In particular, undertake "before and after" surveys of sites where a roading project is constructed.
- In the short-term at least, encourage the use of different simulation packages on rural roading projects, particularly those more suited to specific applications, to obtain the most appropriate project evaluation and to develop experience by practitioners.
- Arrange technical workshops introducing the various modelling options to the roading industry in New Zealand, and providing guidance on how to use them for various project applications.
- Continue to monitor developments in models such as TWOPAS and PARAMICS, and trial them further in New Zealand on suitable rural highway projects. Liaise with the developers where possible to incorporate suitable features for New Zealand use.
- Where possible (i.e. subject to availability), investigate further the suitability for New Zealand rural roads of other potential simulation models identified overseas such as HUTSIM, VTI, AIMSUN, and DRACULA.
- Continue to monitor the development of IHSDM and trial its use in New Zealand, as well as keeping track of other road safety models overseas that may be applicable to New Zealand, either in part or fully.
- Scope the requirements for road safety models in New Zealand at various levels (national/regional strategies, project option scoping, detailed project design, highway audit). Assess the different levels of data collection and output precision required, and whether the same models can be used for different levels.
- Focus rural crash model research in New Zealand initially on curve-related crashes. Other crash types could be predicted using more simple methods at first, with more sophisticated development of these later.
- Identify key unsafe driving actions in New Zealand from an analysis of cause codes and other crash report information. Then observe their prevalence in the normal driving population for comparison with relevant crash statistics.
- Undertake statistical analysis of the relative correlation between crash numbers and potential key indicators of safety. Indicators identified include mean/percentile travel speeds, sight distance requirements, curve/approach speed differences, relative vehicle lane positions, and numbers of aborted or "close" overtaking/intersection manoeuvres and other vehicle "interactions".

- Investigate integrating or linking rural road safety models to existing road design packages, enabling faster specification of road layouts for project assessment. As well as crash reductions, design packages could also evaluate other traditional road user benefits like travel-time savings and vehicle operating costs.

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Appendices

A.1 Sites Surveyed for Field Data Collection

These sites were identified by desktop assessment, then reviewed in the field for their suitability as survey locations in this project. Most sites are in the North Canterbury region (Conway-Rakaia Rivers). Only some have been actually surveyed for this project; survey dates are given for these.

Note: Survey dates indicated with a "*" were surveyed separately from this project.

Note: under "Comments", measured road widths have been annotated "*SealWidth(LaneWidth)*" (in metres).

Survey ID	Targeted Survey Type	State Hwy	Start		End		Description	Comments	Survey Date(s)	Yr.2000 AADT
			RS	RP	RS	RP				
002-0883/05.80	Fuel Consumption	2	883	5.80	946	2.30	Masterton-Featherston-Upper Hutt	Mix of Flat, Rolling, Mountainous terrain	11/6/02	4700
002-0858/08.05	Curve Speed	2	858	8.05	858	8.16	Curve HiSpdEnv RH 25 deg	75k signs both directions	5/6/01*	2600
002-0931/08.99	Curve Speed	2	931	8.99	931	9.09	Curve LoSpdEnv LH 63 deg	45k signs both directions	6/6/01*	5000
01S-0195/21.55	Road Width?	1S	195	21.55	217	0.56	Waiiau River Bridge W8.6m	Good approaches - compare with narrow bridge		2000
01S-0235/11.70	One-Lane Bridge	1S	235	11.70	247	0.14	Hurunui River Bridge W3.7m	150m long, Delay surveys recently carried out - use data	1/3/01*	2100
01S-0247/00.16	Passing Lane?	1S	247	0.16	247	0.56	Incr Passing Lane	On uphill gradient, curved alignment		2100
01S-0247/01.00	Bunching	1S	247	1.00	247	14.00	Rolling Terrain, 13km, 2xPLs	Locate counters at 247/1.0, 247/4.0, 247/9.0, 247/14.0	8/3/02	2100
01S-0247/03.90	Passing Lane?	1S	247	3.90	247	5.00	Incr Passing Lane	On uphill gradient, curved alignment		2100
01S-0262/05.92	Free Speed	1S	262	5.92			Railway Crossing	Train, Intsn, Xing signs; Short straight sth of xing	12/2/02	2200
01S-0284/09.30	Speed Limit?	1S	284	9.30	284	9.70	Amberley 70/50 km/h Nth side	70, 50, Good approach		5900
01S-0303/03.00	Free Speed	1S	303	3.00			North of Saltwater Creek	Good long straight	17/1/02	7000
01S-0303/06.67	Road Width	1S	303	6.67	311	0.36	Ashley River Bridge W6.7m	Slight curve on Nth end	17/1/02	6800
01S-0311/01.11	Side Road?	1S	311	1.11			Tulls Rd RHS, AADT 700	No turn-lanes, humps either side, bridge just sth		6800
01S-0311/01.46	Side Road	1S	311	1.46			Waikuku Beach Rd LHS, AADT 1600	RTB 45+20+100m, slight curve	17/1/02	6800
01S-0311/02.27	Side Road?	1S	311	2.27			Gressons Rd RHS, AADT 900	RTB 45+20+100m		6800
01S-0311/04.52	Speed Limit?	1S	311	4.52	311	5.10	Woodend 70/50 km/h Nth side	Straight approach		8000

ASSESSMENT OF RURAL ROAD SIMULATION MODELLING TOOLS

Survey ID	Targeted Survey Type	State Hwy	Start		End		Description	Comments	Survey Date(s)	Yr.2000 AADT
			RS	RP	RS	RP				
01S-0317/09.92	4-Lane Congestion?	1S	317	9.92	327	0.42	Waimakariri River Bridge W2x9.2m	Obtain automatic speed-volume data from Transit NZ		30000
01S-0347/02.77	Speed Limit?	1S	347	2.77	350	1.39	Templeton 70 km/h Sth side	70, Straight approach		14000
01S-0365/00.17	Passing Lane?	1S	365	0.17	365	1.53	Passing Lanes	Side road at Nth end		12000
01S-0365/02.00	Speed Limit?	1S	365	2.00	365	3.05	Rolleston 80 km/h Sth side	80, Straight approach		9000
01S-0365/04.00	Bunching	1S	365	4.00	365	15.00	Flat Terrain, 11km, 2xPLs	Locate counters at 365/4.0, 365/8.0, 365/11.5, 365/15.0	1/3/02	9000
01S-0365/06.00	Passing Lane	1S	365	6.00	365	7.39	Passing Lanes	Good approaches	22/1/02	9000
01S-0365/08.58	Side Road	1S	365	8.58			Aylesbury/Burnham X-Rd, AADT 2000/500	RTBs 45+20+120m (RH), 25+20+110m (LH)	25/1/02	9000
01S-0381/03.34	Speed Limit?	1S	381	3.34	381	4.15	Dunsandel 70 km/h Nth side	70, Straight approach		8000
007-0028/02.50	Free Speed?	7	28	2.50	28	9.00	Flat Straight Terrain	Minor bumps		2200
007-0028/12.55	Speed Limit	7	28	12.55	28	13.45	Culverden 50 km/h Sth side	50+Name, Good straight approach	12/2/02	2400
007-0028/13.45	Speed Limit?	7	28	13.45	28	13.77	Culverden 70/50 km/h Nth side	70, 50+Name, Good straight approach, can see 50		2400
007-0068/00.73	Curve Speed?	7	68	0.73	68	0.95	Curve 75km/h LoSpdEnv LH 45 deg	Upgrade on Nth side		1100
007-0078/09.80	Straight Gradient?	7	78	9.80	78	10.20	West of Gorge Stream	Incr Down, Good approach, slight LH curve		1100
071-0000/00.50	Overtaking Gap	71	0	0.50	0	6.00	Long straight, 6km	Good sight distance, high traffic, side roads	12/3/02	10 000
073-0015/04.63	Speed Limit?	73	15	4.63	15	5.32	West Melton 80 km/h West side	80+name, Straight approach, curve mid-town		3500
073-0015/13.00	Curve Speed?	73	15	13.00	15	13.30	Curve HiSpdEnv RH 45 deg	Intersection in middle		2400
073-0015/18.22	Speed Limit	73	15	18.22	15	19.00	Kirwee 70 km/h East side	70+name, Straight approach, curve mid-town	1/2/02	2400
073-0034/00.50	Overtaking Gap?	73	34	0.50	34	5.50	Long Straight, 5km	Moderate traffic		2500
073-0041/00.50	Bunching?	73	41	0.50	52	0.50	Flat Terrain, 11km, 0xPLs	Moderate traffic		2000
073-0052/00.97	Speed Limit?	73	52	0.97	52	2.25	Sheffield 70 km/h West side	70, Straight approach		1500
073-0052/12.70	Curve Speed?	73	52	12.70	52	12.90	Curve HiSpdEnv LH 40 deg	75k Decr, Short approach Incr		1400
073-0076/02.10	Curve Speed?	73	76	2.10	76	2.30	Curve LoSpdEnv LH 40 deg			1300
073-0090/11.20	Curve Speed?	73	90	11.20	90	11.60	Curve HiSpdEnv RH 50 deg			1300
073-0107/04.10	Curve Speed?	73	107	4.10	107	4.50	Curve LoSpdEnv LH 40 deg			1300
073-0107/07.90	Straight Gradient	73	107	7.90	107	8.90	West of Ribbonwood Stream	5-6% uphill	1/2/02	1300
073-0121/04.10	Curve Speed?	73	121	4.10	121	4.30	Curve LoSpdEnv RH 35 deg			1300
073-0121/15.37	One-Lane Bridge?	73	121	15.37	136	0.26	Waimakariri River Bridge W3.1m	260m long		1300
075-0000/07.50	Overtaking Gap	75	0	7.50	8	5.00	Long Straight, 6km	Slight curves at 1.5 RH, 3.6 LH	15/2/02	5000

Appendices

Survey ID	Targeted Survey Type	State Hwy	Start		End		Description	Comments	Survey Date(s)	Yr.2000 AADT
			RS	RP	RS	RP				
075-0014/01.00	Overtaking SD	75	14	1.00	35	15.00	Mixed Straights & Curves, 6km		15/2/02	2000
075-0024/08.71	Curve Speed?	75	24	8.71	24	8.86	Curve HiSpdEnv RH 30 deg	55k curve before Incr side		2000
075-0035/02.73	Curve Speed?	75	35	2.73	35	2.85	Curve 65km/h LoSpdEnv RH 35 deg	Long LH curve beforehand		1900
075-0035/06.90	Curve Speed	75	35	6.90	35	7.10	Curve 65km/h HiSpdEnv LH Inc		14/3/02	1900
075-0052/02.50	Bunching	75	52	2.50	61	6.00	Mountainous Terrain, 12km, 3xSVBs	Locate counters at 52/2.8, 52/7.2, 61/3.0, 61/5.5	21/2/02	1100
075-0061/15.00	Straight Gradient	75	61	15.00	61	15.60	East of Takamatua Creek	10-12% uphill	14/3/02	1200
077-0053/06.60	Road Width?	77	53	6.60	53	9.60	East of Windwhistle Corner, W6.2m	6.3(6.1), 6.3(6.1), 6.2(6.0), 6.2(6.0), Minor vert. curves		700
077-0079/00.44	Speed Limit?	77	79	0.44	79	1.40	Glentunnel 70 km/h East side	70, Straight approach		1200
077-0079/01.40	Road Width	77	79	1.40	79	3.70	East of Glentunnel	7.2(6.7)	30/1/02	1200
077-0079/07.30	Road Width?	77	79	7.30	79	9.80	East of old SH77	7.6(7.0), 7.4(7.0), 8.5(7.0), 7.8(7.0)		900
Ayl-SH73 - Two	Road Width?	Aylesbury Rd					SH73 - Two Chain	5.7, 5.6, Low traffic		300
Bal-Maskells -	Road Width?	Balcairn-Amberley Rd					Maskells - Upper Sefton			900
Bur-SH1 - Elle	Road Width?	Burnham Rd					SH1 - Ellesmere Junction	7.5(6.5), Low traffic		600
Eil-Swamp - Bu	Road Width?	Ellesmere Junction Rd					Swamp - Burnham/Bethells	7.3(6.6), 7.4(6.5), 7.4(6.5), Mod. traffic		1000
Lin-Irwell (70	Road Width	Lincoln-Leeston Rd					Irwell (70) - Doyleston (70)	7.2(6.5), 7.4(6.5), Good traffic	1/3/02	1500
Lin-Selwyn Riv	Road Width?	Lincoln-Leeston Rd					Selwyn River - Lake Sth	7.4(6.5), 7.4(6.9), 7.3(6.8), Good traffic		1500
Old-Thompsons	Road Width?	Old West Coast Rd					Thompsons - Intake	7.6, 7.3, 7.0, 7.1, 7.5, 7.6, 8.2, Mod. traffic		1200
Oxf-Bennetts -	Road Width	Oxford-Rangiora Rd (old SH72)					Bennetts - Poyntzs	7.2(6.5), 7.6(6.9), 7.5(7.2), Mod. traffic	12/3/02	700
Oxf-Lilly - Cu	Road Width?	Oxford-Rangiora Rd (old SH72)					Lilly - Cust River	8.3(7.6), 8.3(7.2), 8.0(7.4), Mod. traffic - wide road for comparison		700
Tra-Two Chain	Road Width	Tram Rd					Two Chain - Horrells	7.2(6.0), 6.5(5.9), 7.7(6.4), 7.1(6.3), 6.9(6.5), 7.1(6.3), Mod. traffic	12/3/02	800

A.2 PARAMICS Road Link Categories

The following data is taken from the categories file used in this project for specifying suitable road link types. Explanatory comments are provided as well (##). Note that the number of lanes refers to one direction only; different link types can be specified for each direction.

```
categories: 1 to 40

## Basic 1 & 2 lane rural highway sections with/without opposing overtaking allowed
category 1 lanes: 1 speed: 100 kph width: 4.2 m type: highway overtaking on
colour: 0xffffffff
category 2 lanes: 2 speed: 100 kph width: 7.7 m type: highway colour: 0xffffffff
category 3 lanes: 1 speed: 100 kph width: 4.2 m type: highway colour: 0x00ffef

## Short urban lengths along a rural highway
category 15 lanes: 1 speed: 50 kph width: 6.0 m type: urban colour: 0x00ff00
category 16 lanes: 1 speed: 60 kph width: 5.0 m type: urban colour: 0xb2ff00
category 17 lanes: 1 speed: 70 kph width: 4.5 m type: urban colour: 0xff9800
category 18 lanes: 1 speed: 80 kph width: 4.2 m type: highway overtaking on
colour: 0xff0019

## Other minor rural roads e.g. side roads
category 20 lanes: 1 speed: 100 kph width: 3.5 m type: highway minor overtaking
on colour: 0xffffffff

## Other minor urban roads
category 25 lanes: 1 speed: 50 kph width: 5.0 m type: urban minor colour:
0x00ff00
category 26 lanes: 1 speed: 60 kph width: 4.5 m type: urban minor colour:
0xb2ff00
category 27 lanes: 1 speed: 70 kph width: 4.0 m type: urban minor colour:
0xff9800
category 28 lanes: 1 speed: 80 kph width: 3.5 m type: urban minor colour:
0xff0019

## Curved links with appropriate advisory speeds
category 32 lanes: 1 speed: 25 kph width: 3.7 m type: highway colour: 0x0000ff
category 33 lanes: 1 speed: 35 kph width: 3.7 m type: highway colour: 0x0022ff
category 34 lanes: 1 speed: 45 kph width: 3.7 m type: highway colour: 0x0044ff
category 35 lanes: 1 speed: 55 kph width: 3.7 m type: highway colour: 0x0066ff
category 36 lanes: 1 speed: 65 kph width: 3.7 m type: highway colour: 0x0088ff
category 37 lanes: 1 speed: 75 kph width: 3.7 m type: highway colour: 0x00aaff
category 38 lanes: 1 speed: 85 kph width: 3.7 m type: highway colour: 0x00ccff

## One-lane bridge section (needs to be separately controlled by signals)
category 40 lanes: 1 speed: 30 kph width: 3.7 m type: highway colour: 0xffe14b
```

A.3 PARAMICS Link Attributes for Various Road Sections

This table describes the settings required for various attributes in PARAMICS to obtain the most desirable behaviour (note that values in **bold** are non-default values). To change these, select the desired link, and then select "Modify Link" from the network editor. Refer also to Appendix A.2 for general attributes on default link categories.

Description	No. of Lanes	Urban	Major/Minor	Stay in Lane	Wide End	Wide Start	Force Merge	Force Across	Overtaking	Slip Lane	Visibility	H'dway Factor	Stop Time	End Speed	Lane Merge	Lane Cross	Path Cross
Normal 2-lane O'taking Allowed	1	N	Major	N	N	N	N	N	Y	-	750m	1	0s	-	4s	4s	3s
Normal 2-lane No-O'taking Lines	1	N	Major	N	N	N	N	N	N	-	750m	1	0s	-	4s	4s	3s
Start Taper for Passing Lane	1	N	Major	N	Y	N	N	N	Y/N	-	750m	0.8	0s	-	4s	4s	3s
Passing Lane	2	N?	Major	N	N	N	N	N	N	-	750m	1	0s	-	4s	4s	3s
End Taper for Passing Lane	1	N	Major	N	N	Y	N	N	Y/N	-	750m	0.8	0s	-	2s	4s	3s
Start Taper for Right Turn Bay	1	N	Major	N	Y	N	N	N	N	-	750m	1	0s	-	4s	4s	3s
Right Turn Bay	2	N	Major	N?	N	N	N	N	N	-	750m	1	0s	-	4s	4s	3s
End Taper for Right Turn Bay	1	N	Major	N	N	Y	N	N	N	-	750m	1	0s	-	4s	4s	3s
Left Turn Lane	2	N	Major	N?	N	N	N	N	N	-	750m	1	0s	-	4s	4s	3s
Side Road Approach Intersection	1	N	Minor	N	N	N	N	N	N	?	250m	1	0s	20kmh	4s?	4s?	3s?
Main Road Approach Intersection	1	N	Major	N	N	N	N	N	N	?	750m	1	0s	-	4s	4s	3s
Slow Vehicle Bay	2	N	Major	N	N	N	N	N	N	-	750m	0.8	0s	-	4s	4s	3s
Approach to a Curve (Advis Speed)	1	N	Major	N	N	N	N	N	Y	-	750m	1	0s	AS+10	4s	4s	3s

Notes:

- A link with >2 exits (e.g. approaching crossroads) will be automatically switched to Urban.
- A link with 0, or 2+ exits (i.e. zone connector or intersection approach) will have Overtaking automatically switched off.

A.4 PARAMICS Vehicle Types for NZ use

The following data is taken from the `vehicles` file used in this project for specifying suitable vehicle types. The 18 types are based directly on those used in TRARR for New Zealand situations, as derived by Tate (1995). Note that the "top speed" parameter actually relates to the mean free speed.

```

vehicle types

type 1 OGV2
desc "8-Axle Towing"
Business
weight          38.43 tonne
top speed       90.00 kph
acc             1.36 mpss
inertia        0.790
drag           0.790
dec            -3.00 mpss
## First section
length         4.50 m
front axle     0.80 m
rear axles 2
  axle 1       3.00 m
  axle 2       4.00 m
kingpin        3.25 m

## Trailer details
trailers 2
trailer 1
  length       8.50 m
  rear axles 2
    axle 1     6.25 m
    axle 2     7.50 m
  kingpin      9.25 m
trailer 2
  shape        HGV Trailer
  length       8.50 m
  width        2.50 m
  height       4.00 m
  front coupling 0.50 m
  rear axles 2
    axle 1     6.25 m
    axle 2     7.50 m
  wheel radius 0.50 m
  kingpin      7.75 m
matrix         1
proportion     0.272
perturbation   0.0
familiarity    85.00

type 2 OGV1
desc "6/7-Axle Towing"
Business
top speed       92.00 kph
## First section
length         9.25 m
rear axles 2
  axle 1       7.00 m
  axle 2       8.00 m
kingpin        10.00 m

## Trailer details
trailers 1
trailer 1
  shape        HGV Trailer
  length       9.00 m
  width        2.40 m
  height       3.60 m
  front coupling 0.50 m
  rear axles 3
    axle 1     1.00 m
    axle 2     7.00 m
    axle 3     8.00 m
  wheel radius 0.40 m
  kingpin      8.10 m
matrix         1

```

Appendices

proportion	0.727
perturbation	0.0
familiarity	85.00

type 3 OGV1

desc	"5/6 Axle Combination"
Business	
weight	36.07 tonne
top speed	92.00 kph
acc	1.24 mpss
dec	-3.00 mpss
## First section	
length	7.90 m
rear axles	2
axle 1	6.00 m
axle 2	7.00 m
kingpin	8.50 m
## Trailer details	
trailers	1
trailer 1	
shape	HGV Trailer
length	6.90 m
width	2.40 m
height	3.60 m
front coupling	0.40 m
rear axles	2
axle 1	5.00 m
axle 2	6.00 m
wheel radius	0.40 m
kingpin	8.10 m
matrix	1
proportion	1.100
perturbation	0.0
familiarity	85.00

type 4 OGV2

desc	"5 Axle Artic"
Business	
weight	33.14 tonne
top speed	94.00 kph
acc	1.31 mpss
dec	-3.00 mpss
## First section	
length	5.00 m
front axle	1.00 m
rear axles	2
axle 1	3.50 m
axle 2	4.50 m
kingpin	4.00 m
## Trailer details	
trailers	1
trailer 1	
length	12.00 m
front coupling	1.00 m
rear axles	2
axle 1	9.00 m
axle 2	10.00 m
matrix	1
proportion	0.545
perturbation	0.0
familiarity	85.00

type 5 OGV2

desc	"4 Axle Artic"
Business	
weight	14.96 tonne
top speed	95.00 kph
acc	2.35 mpss
dec	-3.00 mpss
## First section	
length	4.50 m
front axle	1.00 m
rear axles	1
axle 1	3.75 m
## Trailer details	
trailers	1
trailer 1	
length	11.50 m

ASSESSMENT OF RURAL ROAD SIMULATION MODELLING TOOLS

```

height          3.00 m
front coupling  0.75 m
rear axles 2
  axle 1        9.00 m
  axle 2        10.00 m
matrix          1
proportion      1.362
perturbation    0.0
familiarity     85.00

type 6 OGV1
desc "3-Axle Rigid"
Business
weight          11.25 tonne
top speed       95.00 kph
acc             2.97 mpss
dec            -3.00 mpss
length          13.50 m
height          4.25 m
front axle      2.00 m
rear axles 2
  axle 1        11.00 m
  axle 2        12.00 m
front wheel radius 0.50 m
rear wheel radius 0.50 m
kingpin         6.00 m
matrix          1
proportion      1.726
perturbation    0.0
familiarity     85.00

type 7 OGV1
desc "2 Axle Truck Long"
Business
weight          7.79 tonne
top speed       96.00 kph
acc             2.60 mpss
dec            -3.00 mpss
length          12.00 m
height          4.00 m
front axle      1.50 m
rear axles 1
  axle 1        10.00 m
front wheel radius 0.50 m
rear wheel radius 0.50 m
matrix          1
proportion      1.544
perturbation    0.0
familiarity     85.00

type 8 OGV1
desc "2 Axle Truck"
Business
weight          1.99 tonne
top speed       96.00 kph
acc             4.75 mpss
inertia         0.110
drag            0.440
dec            -3.00 mpss
length          6.50 m
height          3.50 m
front axle      1.10 m
rear axles 1
  axle 1        5.50 m
matrix          1
proportion      1.907
perturbation    0.0
familiarity     85.00

type 9 LGV
desc "Utility or Light Van"
Business
weight          1.35 tonne
top speed       98.00 kph
acc             5.46 mpss
dec            -3.00 mpss
length          7.00 m
front axle      0.90 m
rear axles 1
  axle 1        5.25 m
matrix          1

```

Appendices

proportion	4.541
perturbation	0.0
familiarity	85.00

type 10 LGV

desc	"Utility or Light Van"
weight	1.35 tonne
top speed	100.00 kph
acc	5.46 mpss
dec	-6.00 mpss
shape	Minibus
length	7.00 m
width	2.00 m
front axle	0.80 m
rear axles 1	
axle 1	5.25 m
matrix	1
proportion	4.541
perturbation	0.0
familiarity	85.00

type 11 car

desc	"Car & Caravan"
Leisure	
weight	1.49 tonne
top speed	95.00 kph
acc	4.02 mpss
inertia	0.560
drag	0.510
dec	-4.00 mpss
## First section	
length	5.00 m
front axle	0.90 m
rear axles 1	
axle 1	3.90 m
kingpin	5.20 m
## Trailer details	
trailers 1	
trailer 1	
shape	HGV Trailer
length	6.90 m
width	2.00 m
height	3.00 m
front coupling	0.10 m
rear axles 2	
axle 1	4.00 m
axle 2	4.70 m
wheel radius	0.30 m
kingpin	4.10 m
matrix	1
proportion	2.725
perturbation	0.0
familiarity	85.00

type 12 car

desc	"Unaggressive Car"
top speed	100.00 kph
acc	8.40 mpss
dec	-6.00 mpss
length	5.00 m
height	1.70 m
front axle	0.85 m
rear axles 1	
axle 1	3.85 m
matrix	1
proportion	8.174
perturbation	0.0
familiarity	85.00

type 13 car

desc	"Low-powered Car"
weight	1.10 tonne
top speed	102.00 kph
acc	9.80 mpss
dec	-6.00 mpss
length	5.00 m
front axle	0.85 m
rear axles 1	
axle 1	3.85 m
matrix	1

ASSESSMENT OF RURAL ROAD SIMULATION MODELLING TOOLS

```

proportion          9.082
perturbation        0.0
familiarity        85.00

type 14 car
desc "Small Average Car"
weight             0.95 tonne
top speed          102.00 kph
acc                7.00 mpss
dec                -6.00 mpss
length             5.00 m
front axle         0.85 m
rear axles 1
  axle 1           3.85 m
matrix             1
proportion         18.163
perturbation       0.0
familiarity        85.00

type 15 car
desc "Large Car"
weight             1.65 tonne
top speed          102.00 kph
acc                7.00 mpss
dec                -7.00 mpss
length             5.00 m
height             1.60 m
front axle         0.85 m
rear axles 1
  axle 1           3.85 m
matrix             1
proportion         5.449
perturbation       0.0
familiarity        85.00

type 16 car
desc "Average Car"
weight             1.40 tonne
top speed          102.00 kph
acc                8.00 mpss
dec                -6.00 mpss
length             5.00 m
front axle         0.85 m
rear axles 1
  axle 1           3.85 m
matrix             1
proportion         18.163
perturbation       0.0
familiarity        85.00

type 17 car
desc "Average Car"
weight             1.20 tonne
top speed          104.00 kph
acc                8.00 mpss
dec                -6.00 mpss
length             5.00 m
front axle         0.85 m
rear axles 1
  axle 1           3.85 m
matrix             1
proportion         18.163
perturbation       0.0
familiarity        85.00

type 18 car
desc "Sports Car"
weight             1.10 tonne
top speed          106.00 kph
acc                9.00 mpss
dec                -8.00 mpss
length             5.00 m
height             1.40 m
front axle         0.85 m
rear axles 1
  axle 1           3.85 m
matrix             1
proportion         1.816
perturbation       0.0
familiarity        85.00

```