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Application of IHSDM Highway Safety Modelling to New Zealand

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Abstract:

The Interactive Highway Safety Design Model (IHSDM) is a suite of evaluation tools for assessing the safety impacts of geometric design decisions. Developed over almost a decade by the US Federal Highways Administration (FHWA), this publicly available software can help planners and designers identify and assess treatments for potential safety problems on existing or proposed highway sections.

The initial development effort focused on two-lane rural highways, making IHSDM also very applicable to the bulk of New Zealand's state highway network. However a number of tasks have been required to make IHSDM appropriate for New Zealand conditions. These include calibrating the crash prediction model to reflect local patterns, incorporating a set of New Zealand-specific design policies and standards, validating the speed prediction model, modifying the model's vehicle fleet, and developing a means of importing existing road geometry data into IHSDM.

This paper reports on the work required to undertake these tasks and test the revised model's applicability to New Zealand highways. Case studies of actual rural realignments are being used to check IHSDM's practical usability and its crash rate predictions.

About the Author:

Prior to joining Canterbury University as a lecturer in 2004, Glen worked for 10 years as a highways/transportation engineer and traffic researcher for Opus International Consultants Ltd. His wide-ranging research experience includes considerable work on the safety, design and operation of rural two-lane highways, with studies on road geometry and crashes, speed profiles, overtaking demand, and simulation modelling to name a few. Glen also has a keen research interest in sustainable transportation and in particular cycle planning and design. He is currently completing PhD research investigating rural road safety performance measures and the use of road safety models.

INTRODUCTION

Although being a comparatively developed country, New Zealand has both a low population density and relatively difficult terrain. As a result, large roading expenditure has been limited and the country continues to rely largely on two-lane roads of varying standard to link the major urban areas.

Many of these roads have “evolved” from the original pioneer trails, rather than being properly designed for modern motor vehicles. Therefore, they often contain many sub-standard curves out of character with the surrounding environment, as well as a lack of passing opportunities. Both the motoring public and roading authorities have identified these as significant concerns that need to be identified and ultimately remedied.

In evaluating proposals for improving these roads, a key consideration is the expected crash risk of both the existing and proposed alignments. This information helps to:

- (1) prioritise existing sections of road for investigation
- (2) determine the relative cost-effectiveness of different improvement options

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 in rural areas. 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. In an urban environment, drivers are usually more constrained by speed limits and other road users. At higher speeds, sight distances also become more important when considering crashes involving multiple vehicles or unexpected obstructions.

At present, the crash prediction tools available in New Zealand for rural roads are relatively simplistic and more suited to isolated features such as a single curve (e.g. LTNZ 2005). 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 will probably be required to determine the often minor effects of changing small aspects of road alignment or cross-section. These will allow incremental improvements to the relative safety of rural roads to be better identified and incorporated into designs for future works.

This paper reports on the potential of one overseas model, the Interactive Highway Safety Design Model (IHSDM), to be able to assist with the problems outlined above. Work is being undertaken to adapt the model to suit the New Zealand environment and to test the revised model's applicability to New Zealand highways.

BACKGROUND TO IHSDM

IHSDM is a suite of evaluation tools for assessing the safety impacts of geometric design decisions (FHWA 2006). Developed over almost a decade by the US Federal Highways Administration (FHWA), this publicly available software can help planners and designers identify and assess treatments for potential safety problems on existing or proposed highway sections.

The initial development effort focused on two-lane rural highways, with the first public release in 2003. This makes IHSDM also very applicable to the bulk of New Zealand's rural state highway network.

IHSDM consists of several analysis modules, packaged together as a single application with associated support tools:

- 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), to estimate drivers' speed and path choice along a roadway and subsequent measures including lateral acceleration and friction demand (not available yet).
- Intersection Diagnostic Review Module (IRM), which uses an expert system to evaluate intersection design alternatives, and suggest countermeasures to safety problems.
- Policy Review Module (PRM), to verify compliance of designs with specified national/state highway design policies and guidelines.
- Traffic Analysis Module (TAM), to estimate via traffic simulation the operational effects of road designs under current and projected traffic flows, e.g. travel times, time spent following, vehicle interactions.

The results from IHSDM can be reported in a number of different formats. Various text-based reports and graphical plots can be produced and customised to suit. For example, plots can chart road geometry data and also show a speed profile along the highway, which is used by the DCM to identify inconsistencies in speed environment. This plotting layout is very similar to that commonly produced in New Zealand for state highway strategy studies.

APPLICATION OF IHSDM TO NEW ZEALAND

Because of the wide variety in design practices and roading environments from state to state within the US, IHSDM was deliberately designed to allow for local customisation. Bansen & Passetti (2005) describe an example of how the model was customised to analyse a 23-mile two-lane highway in the US. Already other countries (e.g. Canada, Spain) have recognised the ability to also customise it for their own jurisdictions (Robinson *et al* 2005, Castro *et al* 2005). Therefore the IHSDM package appears to be a suitable tool for safety analysis in New Zealand, rather than develop from scratch a road safety model for this country. A similar process could also be used to adapt IHSDM for other jurisdictions, such as Australian states.

A number of tasks have been identified to make IHSDM suitable for use here, including:

- Calibrating the crash prediction model with NZ crash patterns
- Developing a NZ Design Policy file based on local agency standards and guidelines
- Developing an importing routine for NZ highway geometry data
- Modifying the model's vehicle fleet in its traffic simulation module
- Validating the speed prediction routines for NZ conditions

The complexity and detail within IHSDM however means that such customisation requires considerable effort. More detailed discussion about the tasks involved to do this is given in the following sections. Work is ongoing to carry out the necessary calibrations to the package for general use here (Koorey 2002, Keyte 2006).

CALIBRATION OF CRASH PREDICTION MODEL

Harwood *et al* (2000) developed the crash prediction model used in IHSDM for predicting the safety performance of a rural two-lane highway. The CPM algorithm consists of base models and crash modification factors (CMFs) 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 IHSDM base crash model for rural roadway segments is a negative binomial regression model, and includes the following factors:

- Exposure (in terms of million vehicle-miles per year)
- Lane and shoulder widths (feet)
- Driveway density (per mile) and roadside hazard rating (1-7 qualitative scale)
- Degree of horizontal curvature (degrees per 100 ft)
- Vertical gradient (%) and rate of change of gradient (% per 100 ft)

The CMFs adjust the base model predictions to account for the effects on safety for roadway segments of various site features. These features include lane width, shoulder width, shoulder type, horizontal curves, grades, driveway density, two-way left-turn lanes (i.e. "flush medians"), passing lanes, and roadside hazards.

The CPM 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. The CPM also includes an Empirical Bayes procedure that can be applied to weight the safety predictions provided by the algorithm with actual site-specific crash history data.

A calibration procedure is provided for adapting the predicted CPM results to the safety conditions encountered by any particular highway agency. This process allows for adjustment of three factors:

- A scaling factor to adjust the overall crash numbers
- Modification of the relative crash severity proportions
- Modification of the relative crash type proportions

For example, the default IHSDM crash model assumes that ~30% of rural mid-block crashes involve collisions with animals. This is much higher than found in the New Zealand rural highway context (~3% for 2001-2005 rural mid-block road data). Meanwhile, despite both jurisdictions indicating that ~65% of reported crashes are non-injury (property-only damage), IHSDM predicts only 1.3% of all mid-block crashes have fatalities, whereas the equivalent New Zealand data for 2001-2005 gives a figure of double that.

IHSDM provides spreadsheet templates to assist with the derivation of suitable calibration parameters for your jurisdiction. The spreadsheet compares the default predicted number of crashes with the actual recorded crashes, adjusted for the relative traffic volumes and total mileages on roads with different geometries (gradient, curvature, lane width). Simpler calculations can be determined (albeit with less accuracy) where detailed information is not available for some of these parameters. It is important to remember that the ability to directly include historical crash data within IHSDM also helps to calibrate the model to local conditions.

In the case of New Zealand, detailed highway data is available for the state highway network, comprising approximately 10,000 km of inter-urban arterial routes. Work is ongoing to summarise the various road types and crash data on this network, to produce local calibration values for the CPM.

EDITING DESIGN POLICY FILES

IHSDM is currently provided with US Federal standards and guidelines (e.g. AASHTO 2001) on which to base its decisions about design consistency and policy compliance (as used in the PRM and DCM modules). These however are specified in external files, and the program is designed to be able to accept alternative criteria such as state department or local design policies. IHSDM's System Administration Tool allows users to create or edit policy files to use with the program.

Most New Zealand road design is undertaken in accordance with two main guidelines. State highways are managed by Transit New Zealand and are designed using the *State Highway Geometric Design Manual* (SHGDM, Transit NZ 2000). Local Councils generally adopt either the SHGDM or the Austroads *Rural Road Design* guide (Austroads 2003); more often than not, Austroads is used. Transit NZ is also apparently considering looking to use the updated Austroads standards in the near future, and so it was decided to produce a local policy file based on Austroads standards.

Much of the policy file used by IHSDM consists of lookup tables to enable the software to analyse appropriate values. An example of a large lookup table in the Policy File is the Horizontal Curve Elements tab, shown in Figure 1 (also note all of the other tabs).

Figure 1 IHSDM Policy Table Editor

Table: Horizontal Curve Elements

| Max Superelevation (%) | Design Speed (km/h) | Curve Radius (m) | E Flag | E% | Min Runoff (2 Lns) (m) | Min Runoff (4 Lns) (...) |
|------------------------|---------------------|------------------|--------|------|------------------------|--------------------------|
| 6.00 | 60 | 600.00 | NC | -3.0 | 0.00 | 0.00 |
| 6.00 | 70 | 900.00 | NC | -3.0 | 0.00 | 0.00 |
| 6.00 | 80 | 1,250.00 | NC | -3.0 | 0.00 | 0.00 |
| 6.00 | 90 | 1,700.00 | NC | -3.0 | 0.00 | 0.00 |
| 6.00 | 100 | 2,250.00 | NC | -3.0 | 0.00 | 0.00 |
| 6.00 | 110 | 3,000.00 | NC | -3.0 | 0.00 | 0.00 |
| 6.00 | 120 | 4,000.00 | NC | -3.0 | Rate of superelevation | 0.00 |
| 6.00 | 130 | 5,000.00 | NC | -3.0 | 0.00 | 0.00 |
| 6.00 | 60 | 189.00 | VALUE | 3.0 | 29.00 | 0.00 |
| 6.00 | 70 | 309.00 | VALUE | 3.0 | 33.00 | 0.00 |
| 6.00 | 80 | 458.00 | VALUE | 3.0 | 53.00 | 0.00 |
| 6.00 | 90 | 671.00 | VALUE | 3.0 | 60.00 | 0.00 |
| 6.00 | 100 | 875.00 | VALUE | 3.0 | 67.00 | 0.00 |
| 6.00 | 110 | 1,059.00 | VALUE | 3.0 | 73.00 | 0.00 |
| 6.00 | 120 | 1,334.00 | VALUE | 3.0 | 80.00 | 0.00 |
| 6.00 | 130 | 1,566.00 | VALUE | 3.0 | 87.00 | 0.00 |

The creation of a policy file for New Zealand roads has its challenges. For a start, IHSDM has over thirty different data tables to be modified (e.g. default shoulder widths, stopping sight

distances, friction factors), as well as a set of default “scalars” (e.g. minimum lane widths, maximum design speed, driver eye heights). Also, whilst there are many similarities between geometric standards in North America and New Zealand, there are also a number of areas where standards do not directly match.

For example, the Austroads guidelines generally define varying standards based on traffic volumes. Many of IHSDM’s policy sections required different standards by road hierarchy e.g. arterial, collector and local roads. Given that the initial IHSDM assessment within New Zealand was on state highways, the resulting local policy file produced had only one classification, namely Arterial.

IHSDM also seeks more detailed information in some areas than is usually specified by Austroads, e.g. clear zone requirements. Vertical curvature is also quite different, particularly with the required safe stopping sight distances (partly due to differences in driver eye heights). Sometimes, AASHTO and Austroads use different terminology as well, complicating the conversion process. Where no matching Austroads standard could be found, the equivalent IHSDM (AASHTO 2001) values were retained.

Austroads often provides both a table and formula to derive the design standards for differing speeds, horizontal radius, etc. It was decided therefore that the most appropriate way to generate the equivalent tables for IHSDM was in a spreadsheet. This enables formulae to be used to derive the table values, but also allows future users of the policy file to upgrade the values should the Austroads standards change. Updating tables then simply involves copying from the spreadsheet and pasting into the relevant table of the IHSDM Policy Editor.

IMPORTING NZ ROAD ALIGNMENT DATA

IHSDM allows a number of different ways for road data to be created or directly imported into the program:

- Alignment data can be manually entered using IHSDM’s Highway Editor tool, although this can be very time consuming, given the amount of design detail that IHSDM may require.
- IHSDM "comma separated values" (CSV) files can be imported. These are text-based and contain formatted geometric and non-geometric data related to one or more highways. Although these can be created manually, typically they are produced by another IHSDM user exporting a CSV file from another roading project.
- Industry standard LandXML files can be imported (see www.landxml.org for more details). Again, these can be created manually, but most roading design software packages, such as Geopak or MX-Road, can produce LandXML files directly from their alignment data.

Typically the data required by IHSDM comprises geometric elements (such as horizontal curves/tangents, vertical curves/grades and cross-section features), together with general road environment data (such as design speeds, terrain and traffic volumes). For proposed alignments, obtaining this data is usually relatively straightforward as most of the necessary information will already be determined in some road design program. Assessing existing alignments requires further work, and two possible approaches are discussed below.

Where a field survey has been undertaken for a specific realignment project, the user may be able to use that data to assess the existing alignment. However the alignment information is

likely to be recorded as a series of discrete survey points that require conversion to the appropriate geometric elements required by IHSDM. Many roading design packages can readily convert such points to geometric data via a best-fit method controlled by the user. The best-fit method often is not entirely accurate due to the inherent inaccuracies of surveys undertaken at (typically) 20 m centres and the difficulty in visually determining tangent points in the software.

IHSDM's checks for geometric consistency are however not sensitive to absolute accuracies for horizontal and vertical curve radii. A number of variables contribute to the checks for consistency including desired speed, location of curves adjacent to each other and the like. On this basis it was clear from the IHSDM results that the method of visually tracing the survey points and producing geometric elements was generally sufficient for most purposes.

Another approach is to use road geometry data available for the network. Since 1992, New Zealand's state highway network has been regularly surveyed to collect data on horizontal curvature, gradient and cross-fall at 10-metre intervals. This valuable data source has lent itself to a number of novel applications in highway research and operations; Koorey (2005) describes in more detail some of these.

A simple routine can be programmed in a database to "walk" down a given highway dataset and identify the approximate start and end of each geometric element. For example, a cut-off value for horizontal radius (e.g. between 1000 – 2000 m) is used to specify when significant curvature starts, with the curve continuing while radius remains under this value and is in the same turning direction. Once the extent of each curve has been identified, summary information about the road geometry segments within its length can be produced, and a record added to a table of curves.

Generally no attempt is made to identify any spiral (or transition curve) elements either side of a circular curve. As indicated previously, many existing roads in New Zealand were not originally designed in this manner anyway. Also, for most purposes, the limiting values of the central curve are of more interest for analysis purposes (e.g. minimum curve radius, lowest curve speed).

This technique has previously been used to create rural road link data in the PARAMICS micro-simulation model (Koorey 2003). Work is underway to produce a similar conversion procedure for use in IHSDM. This will allow existing sections of state highway to be assessed for safety and consistency. In the meantime, alignment data from roading design software packages can be readily used to test IHSDM.

VEHICLE FLEET UPDATING

Both the Design Consistency and Traffic Analysis modules require the specification of standard vehicles to determine vehicle speeds and interactions along the modelled alignment. IHSDM comes with a pre-defined suite of vehicle classes for passenger cars, trucks and "recreational vehicles". Given the respective differences between North America and Australasia however, it cannot be expected that this vehicle fleet will adequately represent local driving behaviour. For example, many US states operate under a 55 mph (88 km/h) rural speed limit regime, as opposed to New Zealand's standard 100 km/h rural limit. New Zealand also tends to have generally smaller passenger cars than the US.

Fortunately a similar conversion exercise has been done before in New Zealand with the introduction of the TRARR model to this country. TRARR is a simulation model developed

by ARRB for analysing effects of changes in road and traffic characteristics on rural roads (Shepherd 1994). It is commonly used in New Zealand for examining the travel time and vehicle operating costs of various options for improving passing opportunities such as the introduction of passing lanes and realignments. Because the default vehicle parameters are Australian-based, research was undertaken by Tate (1995) to produce a NZ-specific set of parameters. This data would allow for a similar conversion to IHSDM's default vehicle fleet, although it must be acknowledged that the data is now somewhat outdated. A recent project to update TRARR also updated the vehicle fleet data (Taranto 2006), so there may be some scope to use this to inform the conversion process.

For appropriate speed data, New Zealand's Ministry of Transport conducts annual surveys of free speeds on open road straights (MOT 2006). Other recent research has collected vehicle speeds on curves (e.g. Koorey 2003), which can be used to calibrate IHSDM speed predictions. Work is underway to adjust the IHSDM vehicle fleet data accordingly.

TESTING OF IHSDM WITH LOCAL DATA

The initial New Zealand project to be tested using IHSDM is known as the "Awatere Bridge Replacement". The site is located in the upper South Island on State Highway 1, just north of Seddon and 25km south of Blenheim. The existing alignment features a road winding down from the surrounding terraces to a long single-lane bridge across the Awatere River. The new alignment introduces a more sweeping path down to a new two-lane bridge.

The project was primarily chosen on the basis that the electronic alignment data was easily obtainable and the existing horizontal and vertical alignments were substandard. The design was complete over the last 2-3 years to Transit NZ's standards so it could be reasonably assumed that it complied with today's Austroads standards.

The IHSDM software follows a simple process in the evaluation of geometric consistency. This process firstly involves importing and defining alignment data, then choosing a standard to compare the alignment against and finally evaluating the results.

The import data used for this project was extracted from the roading design package MX-Roads. As was described in an earlier section, the process was relatively simple, utilising the proposed alignment elements (designed by the consultant) and the inferred existing alignment elements (best-fit from the field survey points).

The plots below (Figures 2-5) illustrate the respective differences between the existing and proposed alignments, using the Design Consistency Module. As discussed previously, a modified policy file was created that incorporated Austroads standards into this assessment. Whilst the existing alignment has a number of sections with large speed drops or insufficient stopping sight distance (similar calculations can be determined for passing sight distance), the proposed alignment largely eliminates these.

It can be seen that the speed profile in the proposed alignment (bottom part of Figure 4) is far more consistent than the existing alignment (Figure 2), as evidenced by the smaller number of warning "flags" showing. Similarly, the calculated stopping sight distances for the proposed alignment (bottom part of Figure 5) are generally above the "minimum required sight distance" line, unlike those in the existing alignment (Figure 3).

Figure 2 SH1 Awatere Existing Alignment – Speed Profile Consistency

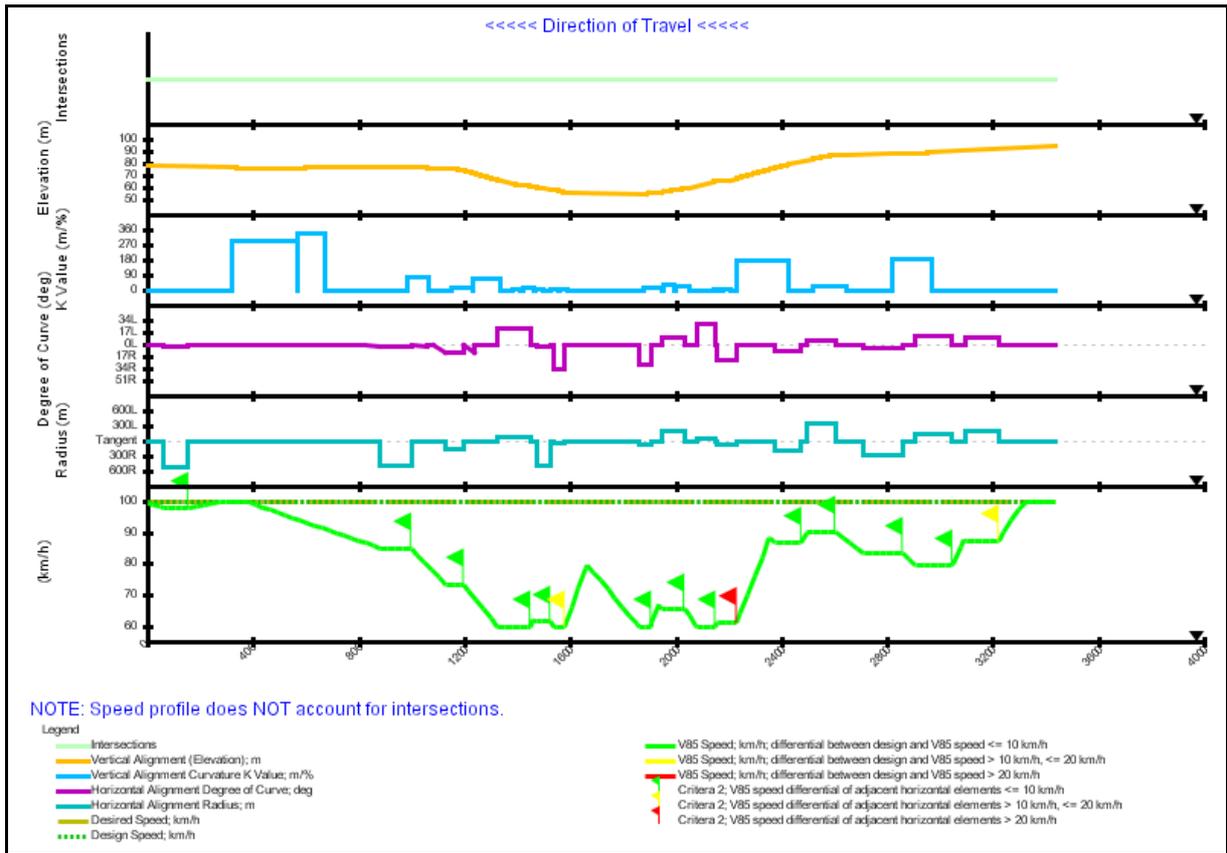


Figure 3 SH1 Awatere Existing Alignment – Stopping Sight Distance Assessment

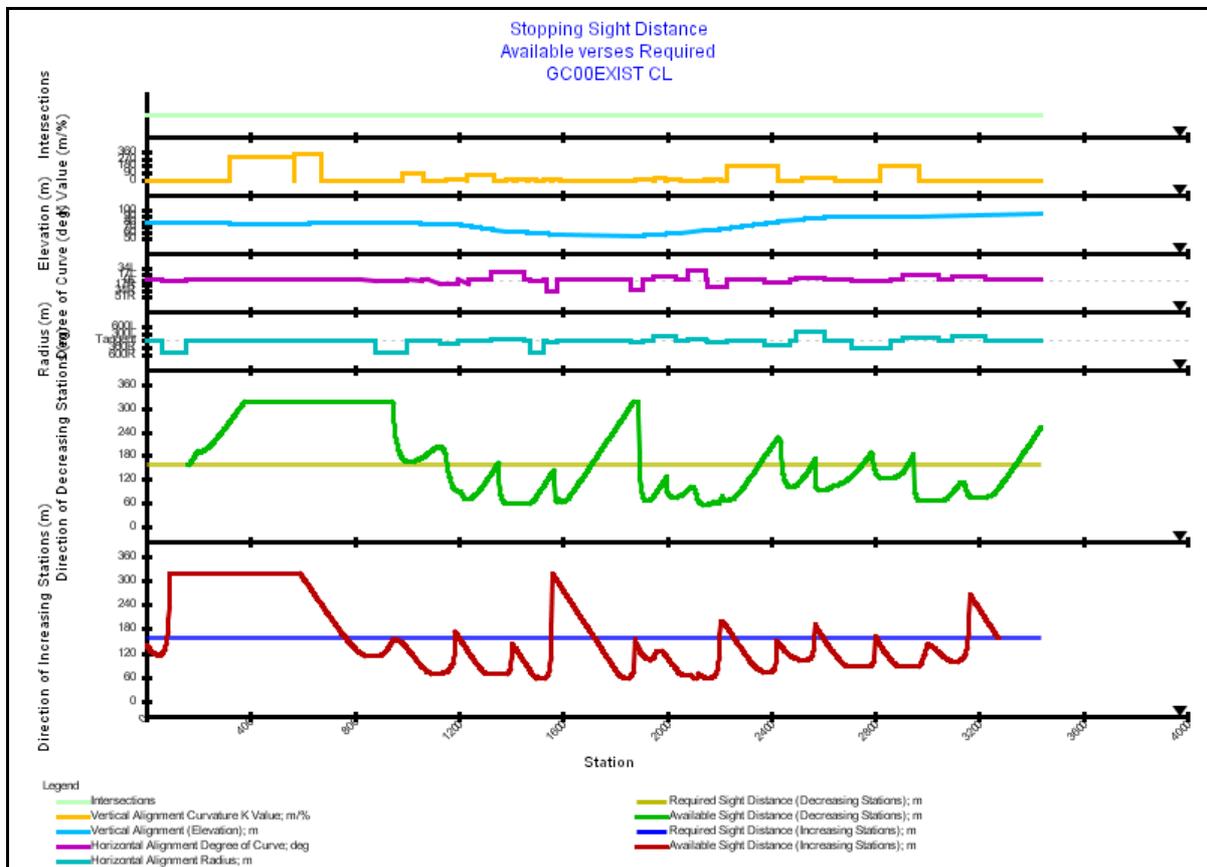


Figure 4 SH1 Awatere Proposed Alignment – Speed Profile Consistency

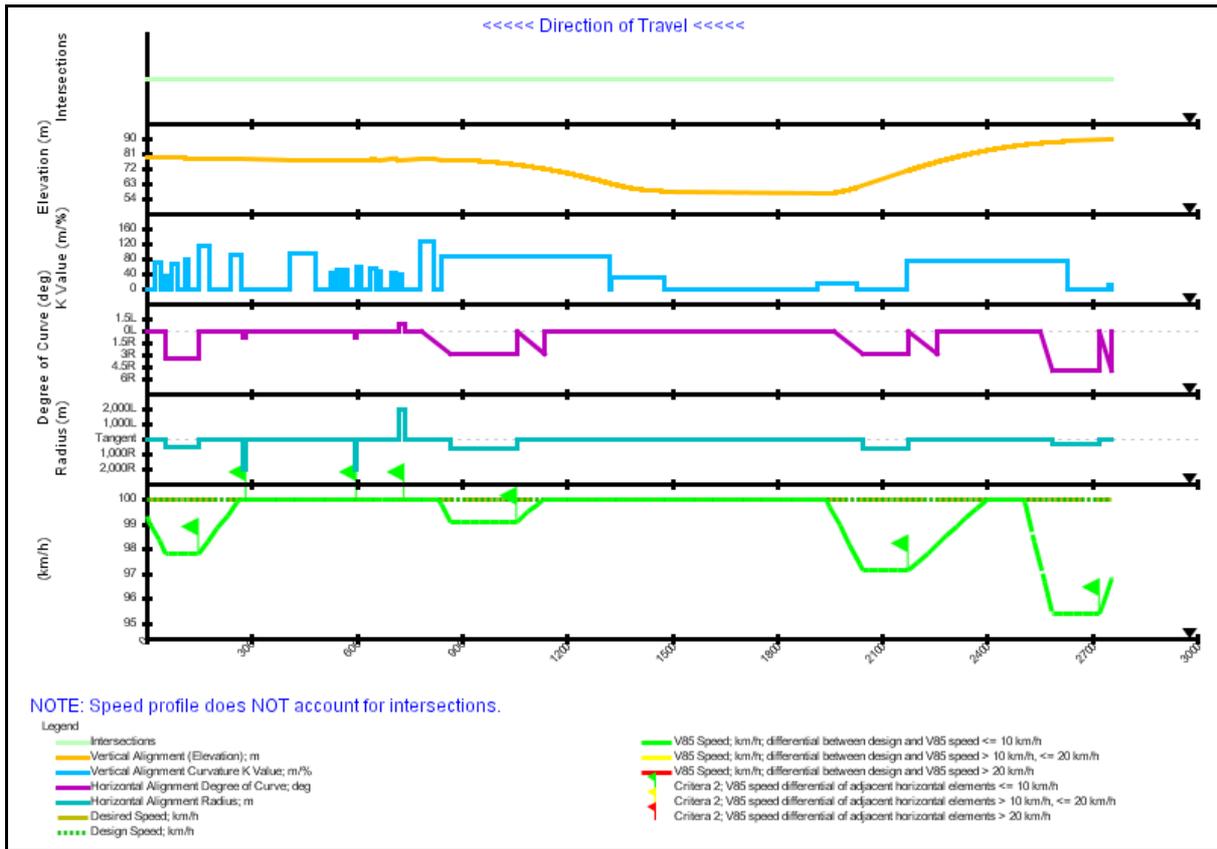
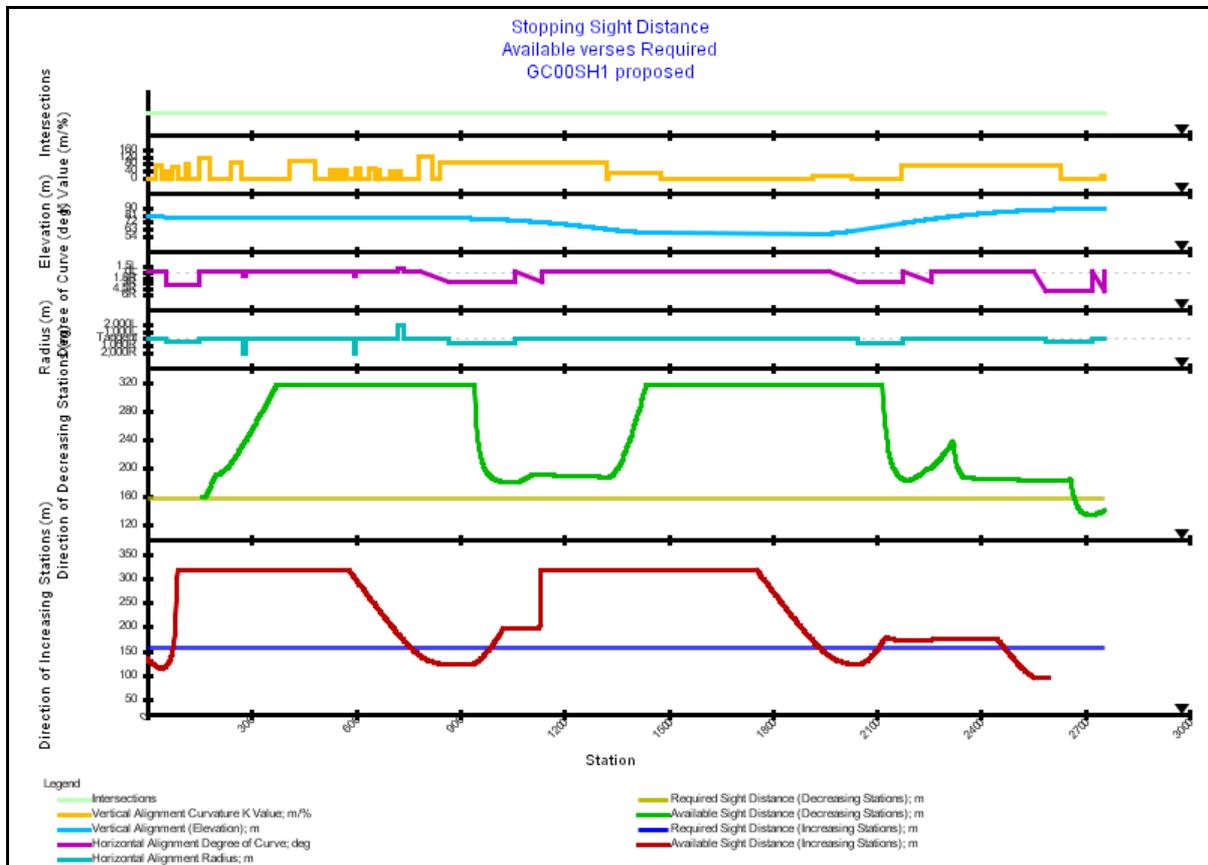


Figure 5 SH1 Awatere Proposed Alignment – Stopping Sight Distance Assessment



The Awatere Bridge highway section is only now under reconstruction (late 2006); hence validation of the crash prediction models for the new alignment can't yet be undertaken. Further testing of IHSDM is planned using other highway sections that were realigned some years ago, where geometry data for both alignments and sufficient before/after crash data is available.

CONCLUSIONS

Initial investigations have shown that IHSDM is a promising tool for safety and operational assessment of highway alignments in New Zealand. Further work is ongoing to carry out the necessary calibrations to the package for general use here. There is likely to be merit in a similar process being used to adapt IHSDM for other jurisdictions, such as Australian states.

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