Report

Review of EEM Passing Lane Length Factors

Prepared for NZ Transport Agency (NZTA) (Client)

By Beca Infrastructure Ltd (Beca)

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1 Introduction

1.1 Purpose

The purpose is to carry out a review of the New Zealand Transport Agency (NZTA, L Cameron) proposals regarding amendments to passing lane (PL) length factors for the EEM Section A7.4.

NZTA's main concern is that Table A7.11 in the EEM provides factors to apply to PL benefits for PLs shorter or longer than the 1.0km length for which the simplified procedure was initially developed, but does not provide for these factors to be modified by traffic volume. NZTA also wishes to use the procedure at a higher range of traffic volume (up to 14,000 veh/day AADT) and over a wider range of PL lengths down to 400m and up to 3.2 km.

To this end, NZTA prepared a spreadsheet analysis which used research findings to generate tables of PL length benefit adjustment factors for a range of traffic volumes, each table cross-tabulated by PL length and spacing.

1.2 Scope of this Report

This report covers Stages 1 and 2 of the offer of service as attached to Contract No. 10-641 of 31 May 2010, and amended by subsequent communications referred to in the contract.

The scope of the investigation is:

(i) Review the spreadsheet as provided and accompanying e-mail explanation for arithmetic and methodology errors;

(ii) Consider the basis of the research cited in Harwood and Hoban (see below), and provide an opinion on whether it is robust and appropriate for the NZ situation.

(iii) If appropriate, suggest a revised Table 7.11 for PL length factors relative to AADT;

(iv) Suggest limits/boundaries for the application of the table, i.e. are the EEM Table A7.11 PL length limits of 750 m -2.00 km still appropriate,

(v) If appropriate, revise the SVB spreadsheet analysis tool in line with the PL procedure changes.

(vi) Brief report/memo outlining relevant matters within items (i) to (v) above including a brief discussion addressing key issues.

The author also wishes to acknowledge Mr Larry Camerom of the NZTA in contributing suggestions and sections to this report (in particular 8, and 10-12) which, as a result, is more extensive than originally envisaged.

1.3 NZTA Background and Key issues

The following background and key issues were provided by NZTA as an introduction to the review that is required.

Background

"An audit has been done on Hukerenui passing lanes (PLs) in Northland. One of the issues raised was the lack of EEM procedures to determine extensions to existing passing lanes.

Surveyed results by Opus Central Labs would suggest that, for a 330m slow vehicle bay (SVB) and a 600 m PL, there was a marked reduction in passing rate at respectively about 150 vph one-way and 260 vph one-way. These one-way flows respectively equate to about 3,000 vpd and 5,300 vpd for 55/45 split and assumed peak hour flow of 9% AADT. If a 10.5% AADT peak hour flow value is assumed to ensure that the peak hour flow is not exceeded for the majority of the time, (rather than for 50% of the time if we use 9% AADT), the AADTs are respectively about 2,500 vpd and 4,500 vpd.

US research has been undertaken on travel time savings for various PL lengths and spacings relative to AADT, (Refer Harwood and Hoban 1987, "Low-Cost Methods for Improving Traffic Operations on Two-Lane Roads", Report No. FHWA/IP-87/2 p.27-33). I have analysed the data and results in Tables 4 and 5 to determine the relative reduction in percentage time delay. My analysis methodology and results are discussed within the attached memo.

In terms of the accuracy of the EEM graphical method, NZ research by Koorey and Gu 2001 "Assessing Passing Opportunities - Stage 2", Transfund Research Report No. 220 shows that the EEM graphs and TRAAR gave similar results at 150 vph one-way but was less effective at 50 vph one-way.

A spreadsheet analysis tool for SVBs has been developed by Beca for NZTA. “

Key Issues

“The EEM Table A7.11 "Factors for passing lane length" doesn't seem to differentiate between levels of AADT. This lack of differentiation means that a shorter 600-800 m PL length is still favoured at higher AADTs. However, intuitively for the same PL spacings, the 1200 -1500 m PLs should become more efficient at higher AADTs. The need for differentiation by AADT is borne out by the earlier mentioned Opus Central Labs research.

Possibly, there are SVB length adjustment factors used in the spreadsheet tool that may have to be revised also.

Regarding limits and boundaries for PL length factors, one of the short-comings of the current EEM procedure is that AADTs 10,000-14,000 vpd are not included, especially 10,000-12,000 vpd. Could the revised PL length factors be provided up to 700 vph (i.e. 12,000 vpd, peak hour 10.5% AADT)? Possibly, how the EEM describes AADT may mean that 700 vph one-way relates to 14,000 vpd (i.e. peak hour 9% AADT). Within any revised table, it may be better to include both one-way flow values as well as estimated AADT (giving directional split and peak hour % of AADT).

Also, it would be useful to extend the PL length factors down to 400 m PLs. While there may have been a desire in the past to have a length difference between 300 m approx max SVB and 800 m minimum PL, this distinction is not appropriate in mountainous terrain with very large speed differentials and a shorter say 450-500 m PL with a longer effective length. In some cases (e.g. very mountainous with large speed differential), it may be a more appropriate to provide a very short 450-500 m PL treatment for AADTs up to about 4,500-5,000 vpd rather than providing longer SVBs (>300 m) at closer spacings.

However, these lower (i.e. ? vpd, 400 m length) and upper (i.e. 14,000 vpd, 3.2 km length) limits would have to be robust in terms of the amount/quality of data obtained and how it compares with the rest of the survey data and results. Possibly, the original research paper can be obtained.

Table A2 and the B1-4 graphs may help with determining the optimum lengths of PL relative to AADT.”

Review Materials Provided by NZTA

The following were also provided for the review; initially

NZTA Excel Spreadsheet: *EEM PL Extension 26-4-10.xls*

Harwood and Hoban (1987) *Low-Cost Methods for Improving Traffic Operations on Two-Lane Roads*, Report No. FHWA/IP-87pp.27-33

Harwood DW, Hoban CJ, and Warren DL, *Effective Use of Passing Lanes on Two-Lane Highways*, Transport Research Record 1195, TRB

and subsequently:

Harwood, D.W. and A.D. St John, *Operational Effectiveness of Passing Lanes on Two-Lane Highways*, Report No. FHWA/RD – 86/195, Federal Highway Administration, 1986

Harwood, D. W., and A. D. St. John, *Passing Lanes and Other Operational Improvements on Two-Lane Highways, Report No. FHWA/RD-85/028*, Federal Highway Administration, Dec 1985.

2 Background to the EEM Passing Lane Factors

The analytical basis for the simplified procedures for assessing PLs was a simulation of traffic queue development over about one third of the State Highway network represented by road geometric measurements from the RGDAS system. These gave horizontal and vertical geometry (x,y,z coordinates) at intervals along the road. The geometry was analysed to estimate the forward driver’s eye view, making assumptions about the unobstructed width either side of the road centreline and taking account of the loss of view due to vertical curvature and horizontal/vertical curve combinations.

A simplified simulation was made using a typical slow/heavy vehicle and typical light/fast vehicle, each of which had performance parameters taken from the NZ Vehicle Operating Cost model and used the HDM-4 speed model speed constraints and acceleration and braking performance.

The distance gap acceptance for overtaking was estimated based upon the speeds of each vehicle type and the speed differential, so that there was a higher propensity to overtake and shorter distance gap acceptance when the overtaken vehicle was on an upgrade and travelling slowly and a lesser propensity to overtake when the overtaken vehicle was travelling relatively fast and/or on a downgrade. Whether overtaking occurred depended upon a suitable gap and no opposing traffic.

The queuing was reset to zero (randomly spaced traffic) at points along the route such as at major intersections, sections of four-laning, or when the road passed through an urban area. The presence of existing PLs was ignored. The comparison between with- and without-PLs was obtained by carrying out the simulation runs with PLs inserted randomly into the network at 5,10 and 20 km spacing, and by running the simulation over a range of traffic volumes. The resulting outputs were analysed by categorising the percentage of road length with passing sight distance against the percentage of queued vehicles and evaluating the extent of time spent queued in platoons and total time delay..

To test the effect of increasing or reducing the length of PLs from the standard 1.00 km that was modelled, the analysis was run at 420 veh/h (two-way), corresponding to 6,000 AADT at the assumed annual hourly flow profile and directional split, and with PLs of 0.75 km and 1.25 km. It is important to note that only one traffic volume was used rather than attempting to run the analysis over a full range of traffic volume/PL length combinations which may have yielded a different set of adjustment factors from those shown in NZTA's Economic Evaluation Manual Appendix A7 Passing Lane section. The report at the time noted that a wider analysis varying PL length and volume together would be needed to produce either a polynomial adjustment formula or a family of curves (or tables) to take account of the combinations of length and volume.

Table 1 – Adjustment Factors (EEM Table A7.11) (at 6,000 AADT)

PL Spacing	Passing Lane Length km				
	0.75	1.00	1.25	1.50	2.00
5km	0.76	1.00	1.15	1.25	1.40
10km	0.74	1.00	1.10	1.24	1.46
20km	0.81	1.00	1.14	1.23	1.47

It can be noted that the simulation analysis output depended on the range of road geometry in the simulation, which included all terrain types. The fact that the graphs of outputs, such as travel time savings, are not completely smooth curves was due to the road characteristics being real data rather than randomly generated. The curves were smoothed when developing the EEM graphs and tables.

However, although the simulation used road geometry from about one third of the NZ state highway network, the simulated results were not calibrated against surveyed field data collected under NZ conditions.

Also, using 420 veh/h as an average hourly flow does not necessarily reflect the average annual benefits for the corresponding AADT. At the estimated AADT of 6,000 veh/day, hourly flows markedly lower than 420 veh/h are likely to have little or no annual benefits. Whereas, hourly flows markedly greater than 420 veh/h are likely to have higher benefits. Therefore, for a given AADT, the accumulated benefits from all hourly flows within a year have to be considered to provide a weighted average of benefits rather than annual benefits based on the typical hourly flow. As mentioned previously, the original analysis by Beca had suggested that a wider range of PL lengths and traffic volumes be used.

NZTA's HNO staff believe that the current EEM Table A7.11 intuitively seems to provide conservatively low adjustment factors for longer PLs (i.e. 1.6-3.2 km) particularly at higher AADT ranges. According to NZTA's HNO staff, NZ research (Cenek & Lester, 2008) commissioned separately by NZTA (then Transit) after the EEM passing lane procedures were developed, suggests that the passing rate for shorter 550 m (on 7% gradient) PLs tended to plateau at about 260 veh/hr one-way compared to longer 1.2 km (on 7% gradient) PLs which seemed to plateau at about 690 veh/h one-way. This NZ research surveyed 5 existing PLs and 1 slow vehicle bay and recorded percentage following and speed at set intervals from about 2 km upstream, within and up to about 12 km downstream of the PL.

The current EEM passing lane length factors do not differentiate between PLs on flat or steep gradients. A 1 km PL on steep gradient should be more effective than a 1 km PL on flat gradient. NZTA's HNO staff have indicated that the AUSTROADS Rural Road Design may be useful as it provides different PL lengths based on different operating speed within the PL, which can be further related to PL lengths within NZTA's Passing & Overtaking Policy for both flat/rolling and mountainous gradients.

3 Basis of the Research and Applicability

3.1 The Research

The body of research referenced is by Douglas Harwood, Chris Hoban and others and was an Australian-American collaboration carried out in the period 1984 to 1988. The research was influential in the development of analytical methods for PLs on two-lane rural roads, notably the TRARR model developed in the context of Tasmanian roads.

3.2 Use of the TWOPAS Simulation Model

The specific research results that are being suggested for application in the EEM simplified procedures are outputs from modelling using TWOPAS, a US-developed passing behaviour simulation program similar in type to TRARR and used in developing the US Highway Capacity Manual. So there is a good pedigree for the research, although it is now 25 years old.

The reasons given for using the TWOPAS simulation base in the summarised research paper (Harwood, Hoban and Warren, 1988) were that field evaluation was not possible for comparison of traffic on a road with/without PLs. At the time, TWOPAS had been validated against field data from two sites in level to moderately rolling terrain and at directional flow rates of between 150 and 500 veh/h. The output characteristics from TWOPAS used to measure effectiveness were the percentage of vehicles delayed in platoons and the percentage of time spent following in platoons, using a less than 4 second headway as the definition of a platooned vehicle. The validation reported in Harwood and St John (1986) gave good agreement for percentage of vehicle delayed in platoons and mean traffic speed at spot locations, but very poor agreement for passing rates within the PL, the simulation giving much higher passing rates than actually experienced.

Just how good a model TWOPAS was in 1987 is not immediately known. Certainly the micro-computing simulation environment in 1987 would have been far less developed than today and the ease of setting up and running simulations would have been more time consuming and costly. For more detail on the simulation methods used in TWOPAS at the time, recourse would be needed to the earlier research report and details of the software.

A comparison of TWOPAS and TRARR has been made by Koorey (2002) which notes various improvements that have been made since the original model, including updating of driver and vehicle characteristics, effect of narrow lanes and shoulders and a major adjustment to automatically generate available sight distance based on user specified offsets to sight obstructions. The number of vehicle types available in the model is more limited than TRARR. The conclusion for TWOPAS was that its appropriateness and practicality for New Zealand use needed to be confirmed.

3.3 Base Conditions for the TWOPAS Simulations

The characteristics of the test section used to develop the results reported in Harwood, Hoban and Warren (1988) are given in the original research report, Harwood and St John (1986). The test section was a hypothetical two lane road section of 8 miles in length in level terrain with the PL located at the start of the section. Other conditions of the simulation were:

- 25% of the length was no-passing zones (which can presumably be equated with length of road without passing sight distance); how these no passing zones were distributed (mean lengths, mean spacing and variance) was not described
- 5% trucks and 5% recreational vehicles (RVs) in the traffic mix, but no other details of the vehicle type mix and performance characteristics (acceleration, braking etc)

- An “average” percentage of platooned vehicles upstream of the test section (the input conditions)
- Directional split was 50/50
- Moderate horizontal curvature and ±1.5% range of gradient
- The criterion used for measuring the percentage of platooned vehicles was the percentage of vehicles passing a point on the highway that are following so closely that their speed is constrained by the leading vehicle; as opposed to the percentage of vehicles with less than a 4 second headway (for reasons of better statistical correlation, sensitivity to the presence of a PL and consistency with the definition of percent time delay in the HCM)

3.4 Main Output Results

The reported outputs from the simulation were families of graphs by flow rates and PL lengths for:

- percent of vehicles delayed in platoons at spot points downstream of the PL start
- percent of time delayed in platoons averaged over the full length of 8 mi
- overall travel speed averaged over the full length of 8 mi

The first output shows how the effects of a PL dissipate downstream, the percent of vehicles delayed gradually converging with the curve for without a PL (Figure 8 in Harwood and St John, 1986). The longer PLs are more effective first by giving a longer length for overtaking within the PL section and having an effect on reducing platooning over a longer length downstream.

The other two outputs (figure 7 in Harwood and St John, 1986) give information that is directly relevant for the EEM analysis, namely:

- the change in overall percent of vehicle time delayed being directly related to frustration benefits, and
- the inverse of change in average travel speed, the change in average delay, being directly related to the time saving benefit.

These last two outputs are given only for the full length of the simulation (8 mi) and not for shorter lengths. An auxiliary table (Table 4 in Harwood and St John, 1986) gives the percentage time delayed in platoons for three effective lengths of PL. This table was initially thought to give percentage time delay for different PL intervals, but this is not the case. All it does is allow the user to substitute PLs with shorter effective lengths than the simulated 8 miles (which coincides with the simulation length), to allow for a variation in conditions such as different traffic mix or geometric features of the road such as steep grades narrow lanes and varying extent of no passing zones for the “without PL” case.

Consequently, only the first part of Table 4 is useful in constructing a table factors to vary the user benefits, and only by parameters of PL length and traffic volume and not by PL spacing.

3.5 Sensitivity Tests

The number of simulation runs was limited to two (2) for each flow rate and PL spacing tested, giving 56 simulation trials over four (4) flow rate and seven (7) PL spacing combinations. With this small number of trials for each data point, a degree of statistical error was likely to be inherent in the results and this is evident in the resulting graphs of outputs.

Sensitivity tests were run for 1.00 km long PLs for:

- The degree of platooning on entry to the test section (low, average, high) – this showed that the effectiveness of the PLs increased with increased upstream platooning at low flow rates, but decreased at high flow rates; a regression equation was developed that explained the majority of the variation. However, as discussed previously, NZ research (Cenek & Lester, 2008) would suggest that this effect is due to the passing rate within shorter PLs starting to plateau at higher hourly one-way flows of 260 veh/h one-way.

- Increase in heavy vehicles from 5% to 20%; increase in recreational vehicles from 5% to 20% - the authors say that this showed no consistent trend of platooning reduction effectiveness. This result is consistent with NZ research (Cenek and Lester, 2008) which could not establish whether the percentage of combined heavy commercial vehicles (HCVs) and light towing vehicles (LTVs) was a significant predictor variable for reduction in percentage following. This lack of a relationship may be due to a scarcity of data but could also possibly be due to the PL sites and their downstream sections being located in a mixture of both steep and flat downstream gradients rather than having a single data set with only steeper downstream gradients (say 5% or more).

- Change from level to rolling terrain with ±4% range of gradients; the percentage of passing sight distance did not appear to be varied when running this sensitivity test – the results again were interpreted to not show any consistent effects, but this too could be due to a lack of data points. However, NZTA's HNO staff believe that the result is consistent with NZ research (Cenek and Lester, 2008 and Roozenburg and Nicholson, 2004), which indicates that there is little effect on HCV speeds within the ±4% range used for the simulation.

3.6 Use of the Research Outputs for Developing EEM Adjustment Factors

The base values of the research outputs should clearly not be used directly for a number of reasons:

- they reflect 25 year old traffic from a country with a vehicle fleet of generally larger engine capacity and heavier vehicles than NZ

- The results are from a simulation over a single and hypothetical test road section where the distribution of no passing lengths is unknown, so cannot be compared with NZ

- The simulation model has not been verified for NZ use and has been updated and developed significantly since the 1987 research

However, it may be acceptable as an interim measure before NZ-based data can be substituted, to use some of the relative effects from this research in tables of modifying factors where the base data relates to NZ conditions.

The performance characteristic used in the research paper to select the most appropriate length of PL for a particular one-way flow rate is the reduction in percentage of time that vehicles are delayed in a platoon as a ratio of the PL length. As noted this is a cost-effectiveness ratio rather than a cost benefit ratio. The implicit assumption is that this percentage of time that vehicles are delayed in platoons is linearly related to the total delay time, each measured over the effective length of the PL, and that PL length is linearly related to cost.

The cost issue does not influence the way in which this research is to be applied, but the use of percent time delayed does matter. The tables and graphs in the EEM simplified procedure are road user costs, including the frustration component which is directly related to percentage of time following in platoons. However, the majority of road user cost savings relate to time savings (TT) in the total journey time and vehicle operating costs (VOCs). TT savings depend on the loss of time (or the speed reduction) when delayed in a platoon as well as the percentage of time in the platoon and other geometric delay in moving between the platooned speed and unconstrained speed.

4 Review of NZTA Spreadsheet

4.1 Description of the Excel Workbook

The Excel workbook has three sheets, with general content as below:

Sheet 1

Sheet 1, Table A1 takes data from Table 2 of TRR 1195 (Table 4 in Harwood and St John, 1986), which is headed “percent time delay” but is in fact “percent of time vehicles spend delayed in platoons”, the data being cross-tabulated by PL length in miles (0, 0.25, 0.50, 0.75, 1.00, 1.50, 2.00) and by effective length (PL length including tapers and downstream length of 3, 5 and maximum of 8 miles). The table is replicated for one-way flows of 100, 200, 400 and 700 veh/h.

The spreadsheet then converts the table data into metric units and transforms the data into “total reduction in percent time delay”, which is the parameter needed to construct Table A7.11 in the EEM. This percentage reduction in total time delay has to then be converted into factors where a 1.00 km PL is the base value, and the factors vary the total time delay savings according to longer or shorter PLs.

The Table 2 values for effective lengths of 8, 5 and 3 miles have been incorrectly interpreted to be PL spacings at 8 and 5 kms and used to interpolate and extrapolate for PL spacings of 5,10 and 20 km. This misinterpretation is understandable as TRR 1195 is not very clear in what is being presented. Only the 8 mi values represent the TWOPAS simulation and the values for 5 and 3 miles are for different (and unmeasured) traffic and geometric conditions.

The hourly flows have been converted to AADT assuming 10.5% peak hour factor and 55%/45% directional split, although the indicated AADTs are not exactly (100 and 200 veh/h in particular). The AADTs do not agree if 12% peak and 60%/40% directional flows are used. Possibly, one-way peak hour flows is a better way of relating flow to US research values of reduced percentage following and speed.

The total reduction in percent time delay is then calculated by subtracting the with-PL value of percent of time vehicles spend delayed in platoons from the without-PL value. (This is also shown as a proportion of the PL length with an inclusion of 0.11 km for tapers, but this ratio is not used.)

Table A2 takes the results from Table A1 and converts them into a form to show the percentage of vehicles experiencing time delay as a proportion of PL length as an incremental change with PL length. This shows up the point of maximum cost-effectiveness (based on percentage following) in the same way as the research paper, but is not used further.

Sheet 2

Sheet 2 provides plots of the results from Sheet 1, Table A1 as families of curves which can be useful to view whether there are discontinuities in the curves that may point to a problem. For some reason the data are not linked back to Sheet 1, although the same values are used on both sheets.. The curves don’t show up any obvious problems, apart from a slight reversal of curvature in the 400 veh/h family of curves

Sheet 3

Sheet 3 gives tables of PL length factors, first as percentage time saving from Sheet 1 Table A1 and then normalised around the 1.0 km PL value of 1.0. Again the values have not been directly linked back to Sheet 1, although the same values are used on both sheets. The intention is that these normalised factors be substituted for EEM Table A7.11. The table includes interpolation for intermediate values of PL spacing and extrapolation from 8mi (12.8 km) to 20km. As noted, this is from a misinterpretation of the data and is not valid. The author believes that any table of relative values (derived from US data) should be checked against NZ conditions.

Therefore, data obtained from research into the operational performance of NZ passing lanes (Cenek & Lester, 2008), which was undertaken after preparation of the EEM PL procedures, will be used to check the calibration points on the table of relative US-derived values. This calibration check will involve NZ-derived values for PLs with similar lengths and one-way traffic volumes to the US calibration sites. This check is described later within Section 8 Calibration to NZ Conditions.

4.2 Discussion

The resulting factor tables have been plotted in Excel to see whether they form well behaved families of curves. There appear to be some anomalies such as the peak at 13km PL spacing for 100 and 200 veh/h flow rates, and an up-kick in the plot for 3.2km length PLs at high flows for longer spaced PLs.

5 Appropriateness of the Method

Our conclusion is that despite the research being 25 years old, from a significantly different vehicle fleet and involving a simulation of hypothetical road section with a limited number of simulation trials, it is nevertheless useful in developing a set of modifying factors for PL length and traffic volume for the EEM relative to a base analysis that uses NZ data. It would not be suitable as a source of values rather than as relative factors. The tables so developed should be regarded as an interim measure for the EEM until more extensive NZ-based analysis either simulation-based, empirical studies or both, can be undertaken. Also, as noted, there is no basis for distinguishing between factors for different PL spacings.

The approach taken allows two sets of modifying factors to be developed:

(i) For factoring driver frustration benefits – tables based on change in percentage of time spent following as developed by NZTA.

(ii) For overall travel time (TT) and vehicle operating cost (VOC) benefits – tables based on change in the total time delayed

In each case the tables are relative to the base case of a 1.00 km long PL. One set of factors will be used for all PL spacings, there being insufficient information to distinguish differences in the factors, if any, for 5, 10 and 20 km spacings.

6 Boundaries of Application

The boundaries of the EEM method for evaluation of individual PLs and the simulation from Harwood and St John (1986) compare as follows:

Table 2 – Boundaries of Application of EEM and Harwood Research

Parameter	EEM		Harwood and St John	
	Max	Min	Max	Min
Hourly directional volume	700	140	700	100
Directional Split	60/40 (rural recreational)	55/45 base case	50/50 only simulated	
AADT	10,000	2,000	not specified	
Terrain	Mount	Flat	Rolling	Flat
Passing Sight Distance	Tables across range of passing sight distance		25% no passing zones in simulation	
% heavy/slow vehicles	adjustment of ± 1% of road user benefits per percentage point change of HCVs around 12%		5% trucks, 5% RVs base value, inconclusive sensitivity to 20%/5% and 5%/20% trucks/RVs	
PL length	1.75	0.75	3.20	0.40
PL spacing, km	20	5	not tested	
Upstream platooning	Data generated within simulation but not analysed		70% delayed	20% delayed

Traffic volume - The research underlying the EEM simulated hourly directional flows of 140, 280, 420, 560, 700 and 1400 veh/h in aggregating flows over an annual flow profile in six flow periods (17.5%, 14.0%, 10.5%, 7%, 3.5% and 0.9% of AADT), although the simulation results at 1,400 veh/h one-way tested the limits of the model. While EEM tables of AADTs of only up to 10,000 veh/day were developed, it would be possible to extend the volumes up to 14,000 AADT. The Harwood and St John research did not deal with daily flows.

NZTA wishes to extend the PL length factor table up to 14,000 AADT. This extension would require some extrapolation beyond the one-way traffic volumes tested in the US research, which were 130 vph one-way for site R11 unknown length on flat gradient and 410 vph one-way for site R02 Nbd 1.64 km PL on flat terrain. To minimise errors in the extrapolation of results, data from NZ sites will be used to help calibrate the US-derived table against NZ conditions, namely:

- Site 2e, 550 m PL, 101-350 veh/h one-way, 2,500-8,500 veh/day approx, 6.8% gradient,
- Site 6e, 1.2 km PL, 301-750 veh/h one-way, 7,000-18,000 veh/day approx, 7.2% gradient.

Site 5f is a 1.4 km PL with surveyed data collected over the flow range 301-450 veh/h one-way (7,000-11,000 veh/day approx) and lies on a 0.3% gradient. Site 5f will be used to check sites 2e and 6e against gradient effects.

Terrain – the EEM simulation used the RGDAS geometry from about one third of the state highway network and sorted the outputs into terrain categories as well as categories of passing sight distance, which had a much more dominant effect on road user costs than did terrain. The US research was only for flat to rolling terrain.

Passing Sight Distance – the US research was for 25% "no passing" zones, although it was not clear what these represent and this percentage is low, even for flat terrain. The 25% may be zones where traffic markings and signing prohibit overtaking, so may understate the conditions of acceptable passing sight distance. Other than the table for different effective lengths, which was constructed by combining outputs from the simulated section, different passing sight distance conditions were not tested in the simulation.

Percentage Heavy/Slow Vehicles – the US research was for a base simulation with 10% trucks and recreational vehicles (RVs), compared with 12% in the EEM tables.

Passing Lane Length – the US research simulation modelled PLs as short as 400m and as long as 3,200m which was a greater range than the 750 to 2,000m in the EEM. This gives a reasonable basis for extending the EEM range. Short PLs were purposely not included in the EEM to preserve the distinction from slow vehicle bays, which are designed to operate differently. Longer PLs and higher AADTs were not considered but an extension is desirable to cover the range of auxiliary lane operation up to continuous 2+1 layouts.

Passing Lane Spacing – this was tested empirically in the EEM simulation, giving the values shown in EEM Table A7.11. The variation in the modifying factor by PL spacing was relatively small, a maximum spread of 10% for the 750m spacing and only 2% to 5% in the other spacings. The US research, as noted, does not provide information that can be directly used to generate tables of modifying factors by PL spacing.

Upstream Platooning – The EEM simulation reset the traffic stream platooning to random inter-vehicle distribution at main change points such as urban/rural boundaries and main intersections. The platooning conditions on entry to a PL section then depended on the passing sight distance conditions upstream, the PL separation, and traffic volume. However, this data was not separately collected in the simulation output so cannot be readily compared against the US research. The US research applied "average" platooning levels for different directional flow rates from the following table.

Table 3 - Upstream Platooning from Harwood and St John (1986)

Flow Rate, veh/h	Low	Average	High
100	10	20	35
200	20	35	50
400	35	50	65
700	50	65	70

The upstream platooning conditions clearly will affect the shape of the graphs in Figure 8 of Harwood and St John (1986). It is notable that the upstream platooning for both traffic volume levels is much lower than the downstream platooning at 7 mi from the PL start. In fact the upstream platooning level is reached only 0.5 to 1.0 km downstream of the PL end, implying a very rapid reformation of queues. The percentage of vehicles delayed asymptotes to around 80% for 400 veh/h and 85% for 700 veh/h. These results also seem at odds with the 25% no passing zones claimed for the simulation section. Some sensitivity tests were run on upstream platooning and a regression model developed and presented as tabulated data (Table 6 in Harwood and St John, 1986).

NZTA’s HNO staff have observed a similar effect in work undertaken by Cenek and Lester, which had a series of survey locations generally at 2 and 0.2 km upstream, within the PL, as well as 0.2, ≈2, ≈4.5 and ≈12 km downstream of the end of merge taper. There were markedly high percentage following values at 0.2 km downstream of the PL merge taper end with the lowest percentage following values generally at 2 km approximately downstream before a progressive increase in percentage following further downstream. This effect was probably due to a reordering of the platoon but insufficient distance at 200 m downstream for this reordering to show any change in percentage following. For that research, the percentage following values recorded at 200 m downstream of the PL merge were not considered when comparing upstream and downstream percentage following.

7. Comparison of US Research and EEM Method

A comparison has been made of the US research data with the PL length factors in the existing EEM Table A7.11. To make this comparison the US data, which is for hourly one-way flows and PL lengths in miles, was transformed to the AADT values given in the EEM method and PL lengths in metres. This then allowed a comparison to be made between the factors in EEM Table A7.11 and the US research results at the 6,000 AADT on which the EEM table is based, and for a range of PL lengths around the base length of 1.0km. This section describes how the data transformation and comparison was carried out.

7.1 Table for Travel Time and Vehicle Operating Cost

The graphs of overall vehicle speed versus flow rate for different PL lengths from Harwood, D.W. and A.D. St John (1986), Figure 7, were first converted to a tabular form. The average speed over the 8 mile simulation length against hourly one-way flow rate (100, 200, 400 and 700 veh/h) for each PL length (none, 0.25 mi, 0.50 mi, 0.75 mi, 1.00 mi, 1.50 mi and 2.00 mi) was fitted to a family of third order polynomial equations.

The polynomial was not constrained to pass through the origin as this gave a much larger deviation from the original graph data. At the upper end of flows, the data were extrapolated to 1050 veh/h using the linear trend derived from 400 and 700 veh/h data points. In constructing the family of curves, a small amount of manual smoothing of the data was carried out first to remove evident inconsistencies originating from the limited number of original simulation runs.

As discussed later in Section 8 Calibration to New Zealand Conditions, the US results were only calibrated from sites with 130 veh/h one-way and 410 veh/h one-way. A better result would later be obtained by using data from NZ research that was surveyed over a wider range of traffic volumes (i.e. site 2e 101-350 veh/h one-way and site 6e 301-750 veh/h one-way). A drop off in performance was picked up at about 250 veh/h for an equivalent 800 m PL (site 2e) and about 675 veh/h for an equivalent 1.6 km PL (site 6e).

Third order polynomial curves were also used at each one-way volume level across the range of PL lengths to model intermediate data points for metric PL lengths of 0.40, 0.80, 1.20, 1.60, 2.40 and 3.20 kms. These modelled data points were then used to generate third order polynomial curves for each metric PL length across the range of hourly one-way traffic volumes. However, it was later decided to restrict values to 400-2,000 m PLs as the NZ calibration sites were equivalent to about 800 m on flat gradient and 1600 m PL on flat gradient. Therefore by calibrating using NZ data, the errors from extrapolation would be minimised, given that the lower and upper limits of PL lengths within the table would be about 400 m difference from the PL lengths at the calibration sites.

As the EEM table of PL length factors versus AADT is constructed from a weighted average of annual hours, traffic volume bands and delay, the US data had to be treated in the same way, using the annual hourly flow distribution for rural roads with low volumes of recreational traffic as given in Table A7.2 in the EEM. As this distribution is for two-way flows, an assumption had to be made of the directional split at each flow level with a 50/50 split assumed for the lower flow periods varying up to a maximum of 65/35 split at the extreme high peaks.

The average speeds were then converted to delay per km and as differences from the "without PL" values. Finally the delay differences were converted to modifying factors for each flow point based on a factor of 1.00 for a 1.0 km PL.

7.2 Table for Driver Frustration Cost

A similar process was followed for deriving the table of modifying factors for driver frustration costs, but based on Table 4 from Harwood and St John (1986) of percent time spent following, again using the values from their simulation (that is for 8 mile effective length).

Again a third order polynomial equation was fitted to the percent time delay in platoons against flow rate for each PL length, with a value for the 1050 hourly one-way flow point obtained by linear extrapolation from the 400 and 700 veh/h data points. The values for metric PL lengths were generated in the same way as in para 0 above.

The percent time delayed values corresponding to the hourly flows for each value of AADT were then generated from the families of curves and aggregated over the hours for each flow level per year in a weighted mean calculation, again as in para 0 above.

7.3 Comparison with EEM Table A7.11

Comparing the results of this transformation of the US data with the existing EEM Table A7.11, which was for a base flow of 6,000 veh/day AADT, in Table 4 below, the implied adjustment factors agree for the 750m PL but are some 10% to 20% higher for PL lengths over 1.00 km. There was no distinction made in the EEM on the application of the factors to travel time savings or to driver frustration benefits. However, time savings provide the majority of benefits so should be taken as the main point of comparison.

Table 4 – Comparison of Old and New Values, at 6,000 veh/day AADT

PL Length, m	from US Data		Existing EEM Table A7.11	Existing/New	
	Travel Time and VOC	Driver Frustration		Travel Time and VOC	Driver Frustration
750	0.76	0.71	0.74	0.97	1.04
1000	1.00	1.00	1.00	1.00	1.00
1250	1.22	1.20	1.10	0.90	0.90
1500	1.42	1.33	1.24	0.88	0.93
2000	1.76	1.56	1.46	0.83	0.93

The US values have been adjusted downwards so that US and EEM factors are the same at 6,000 veh/day. For each individual PL length, the same PL length factor is used regardless of traffic volumes. Tables 5 and 6 show the derived PL length factors for both TT/VOC savings and frustration cost savings. The workings behind Tables 5 and 6 are provided within the supporting spreadsheet.

Table 5 - Derived Factors for Travel Time & Vehicle Operating Cost Savings

AADT	Passing Lane Length							
	400m	800m	1000m	1200m	1600m	2000m	2400m	3200m
2,000	0.39	0.91	1.00	1.17	1.13	1.18	1.16	1.35
4,000	0.33	0.86	1.00	1.19	1.40	1.55	1.65	1.93
6,000	0.30	0.80	1.00	1.21	1.54	1.76	1.91	2.25
8,000	0.27	0.80	1.00	1.22	1.63	1.88	2.08	2.46
10,000	0.25	0.78	1.00	1.24	1.69	1.97	2.2	2.62
12,000	0.23	0.77	1.00	1.25	1.73	2.04	2.29	2.74
14,000	0.22	0.76	1.00	1.26	1.76	2.08	2.35	2.84

Table 6 - Derived Factors for Frustration Cost Savings

AADT	Passing Lane Length							
	400m	800m	1000m	1200m	1600m	2000m	2400m	3200m
2,000	0.17	0.87	1.00	1.13	1.52	1.71	1.89	1.99
4,000	0.14	0.82	1.00	1.18	1.41	1.59	1.78	2.10
6,000	0.12	0.80	1.00	1.20	1.37	1.56	1.75	2.20
8,000	0.12	0.79	1.00	1.21	1.38	1.58	1.77	2.31
10,000	0.12	0.79	1.00	1.21	1.40	1.61	1.82	2.44
12,000	0.13	0.79	1.00	1.21	1.43	1.66	1.89	2.56
14,000	0.14	0.79	1.00	1.21	1.47	1.71	1.95	2.68

The question is then whether a further modification, if any, should be made to the US derived adjustment factors to bring them into line with the existing New Zealand practice. This is considered in the following section, where other New Zealand empirical data is compared with these simulation-based results.

8. Calibration to NZ Conditions

8.1 US Sites

Further investigation by NZTA's HNO staff of the two calibration sites within the US research (Harwood & St John, 1985), shows that one site was two 1.64 km PLs in parallel (R02 Nbd and Sbd) with an average hourly flow of about 410 and 415 veh/h one-way respectively (surveyed ADT 9,800 vpd). The other PL of unknown length (R11) had an average of about 130 veh/h one-way (surveyed ADT 2,970 vpd) and was assumed to be shorter. Up to six hours was collected for each site within the study. The proportion of average hourly flow was about 7.6% of ADT for both sites.

Therefore, journey time delay and percentage following values for shorter PLs (i.e. 0.4-1.2 km) at higher one-way flows of say 400 veh/h or more are likely to be extrapolations and may be prone to error. Similarly, values for longer PLs (i.e. 1.6-3.2 km) with lower one-way flows at say 200 veh/h or less are likely to be extrapolations and may also be prone to error.

8.2 Selection of NZ Sites

NZTA's HNO staff has provided Table 7 and the following commentary. Table 7 shows a comparison of percentage following immediately upstream of the PL, as well as the difference between upstream-downstream percentage following and is drawn from other NZ research (Table 9 of Cenek & Lester, 2008). The percentage following is taken at the 4 second criterion for both NZ and US values. PL length excludes tapers.

From Harwood and St John 1985, site R02 Sbd achieved low passing rates in the first part of the PL due to poor road geometrics. Therefore, R02 Sbd's percentage following values are lower compared to the Nbd direction and should be excluded from any further comparison.

Site 3e was excluded as the passing rate was erratic at lower flows (100-200 veh/h one-way) compared to site 2e with a similar PL length and gradient. This difference was probably due to both poor approach sight distance at the beginning of the site 3e PL and fluctuations in upstream demand. Therefore, site 3e percentage following values should be excluded from any further comparison.

Site 8j was excluded from the comparison between PLs but it does provide an indicative result for passing facilities at 100-150 and 150-200 veh/h one-way, although a PL of similar length and gradient is expected to be more efficient.

While the US values used to calibrate the TWOPAS simulation and the NZ data used as a comparison both have higher % HCV+LTV values than the assumed simulation conditions of 5% HCVs and 5% LTVs, this difference is not expected to markedly affect the relative US tables as the simulations also assumed flattish gradients of +/-1.5% and +/- 4.5%. Over these gradient ranges, the proportion of HCVs and LTVs are not expected to have a marked effect.

Table 7 - Comparison between US and NZ values for Percentage Following Immediately Upstream and Difference Upstream-Downstream Percentage Following

Site	Length (m) Gradient (%)	Hourly Records	Percent HCV & LTV (%)	One way Flows (vph)	Upstream Percent Following	Difference in Percent Following
Site 8j (NZ)*	330 (6.4)	5	15	151-200	33.0	1.9
		21	19	100-150	27.0	5.0
Site 3e (NZ)*	560 (5.7)	25	20	101-200	34.1	2.8
Site 2e (NZ)	600 (6.8)	10	10	301-350	50.6	3.2
		12	12	201-300	45.0	5.7
		11	11	101-200	32.3	5.5
R11 (US)	? (0-3)	6 max	30 #	130	34.2	2.8
Site 5f (NZ)	1400 (0.3)	11	18	401-450	54.9	4.6
		20	17	301-400	50.3	5.7
Site 6e (NZ)	1190 (7.2)	5	10	701-750	68.0	4.4
		5	13	651-700	66.3	4.9
		14	13	301-400	45	7.9
R02 Sbd (US)*	1640 (0-3)	6 max	16 #	415	46.1	3.5
R02 Nbd (US)	1640 (0-3)	6 max	17 #	410	51.4	5.6

Note: * = Sites 8j, 3e & R02 Sbd were excluded. # = % Trucks and RVs.

8.3 Conversion of One-Way Flows to AADT

The US peak hour one-way traffic flow values used to calibrate the derived table of US values equate to a peak hour flow of 7.6% of ADT. This US 7.6% value is close to 7% AADT, which is the peak hour flow value that occurs on the majority of NZ rural strategic roads.

To be compatible with the one-way flows and ADT values used to calibrate the US relative tables, a 55%/45% directional split and 7.6% AADT value has been used to convert one-way flow to AADT for NZ values.

Therefore for site 2e at 250 average veh/h one-way, the estimated AADT is about 6,000 vpd and for site 6e at 675 average veh/h one-way, the estimated AADT is about 16,000 vpd.

8.4 Performance Threshold

Taking into account performance drop-off relative to length and AADT, Figure 4 within Cameron, Cenek and Wanty, 2008 showed that at the mid-point of the PL, the passing rate for site 2e started to plateau at about 250 veh/h one-way (201-300 interval, 24% of one-way flow passing) with no additional increase in passing rate at 325 veh/h one-way (301-350 interval, 24% of one-way flow passing). Similarly, for site 6e, the passing rate started to plateau at about 600 veh/h one-way (25% of one-way flow passing) with a slight increase in passing rate through to about 775 veh/h one-way (28% passing).

As a comparison, Table 6 within Cameron, Cenek and Wanty, 2008 showed that the PL became ineffective regarding the downstream operational length for sites 2e and 6e for 260 veh/h and 688 veh/h one-way flow respectively, which are similar to flows for plateauing of the passing rate. The operational length is defined as the distance downstream from the merge taper end until the downstream percentage following was the same as the upstream percentage following.

The larger change in upstream-downstream percentage following values for site 2e at low flows is probably due to the next incremental flow range being a greater proportional increase. The lower number of hourly recordings at higher one-way flow ranges may also be a contributing factor.

8.5 Gradient Effects

US site R02 is on a flattish gradient and it is unclear for US site R11. For NZ sites 2e and 6e the gradient is similar (i.e. 6.8% and 7.2% respectively). NZ site 5f is on a gradient of about 0.3%. Comparing NZ site 5f (301-400 veh/h one-way so 375 average veh/h) and US site R02 (410 veh/h one-way), the change in upstream-downstream percentage following is similar (i.e. 5.7% versus 5.6% respectively) for similar levels of upstream percentage following (i.e. 51.5% versus 50.3%).At these lower traffic volumes, the length of NZ site 5f is assumed to be less of an influencing factor. Therefore, on flat gradients the US and NZ values are similar.

At 301-400 veh/h one-way (say 375 average veh/h), site 6e has an upstream-downstream change of about 7.9%. The main difference is probably due to gradient, as site 6e is 1200 m long excluding tapers and therefore shorter. Possibly, part of the higher value may be due to the upstream traffic signals, which means that the platoon does not necessarily have the slowest vehicle at the front.

Based on some speed survey work for a steep PL on SH 2 Napier to Gisborne (north of Kareaara Bridge) the 94 km/h overtaking speed compared to 75 km/h for overtaken Type 2 and larger vehicles and 90 km/h overtaking speed compared to 66 km/h for overtaken Type 7 and larger vehicles (i.e. B-Trains, articulated semi-trailers, etc). Therefore an assumed 90 km/hr general operating speed and 20 km/h speed differential seems appropriate.

Table 8 shows AUSTROADS PL lengths relative to operating speed. Based on Table 8, at higher AADTs, site 6e is assumed to have about a 90 km/hr operating speed environment and approximates to about a 1600 m PL on flat gradient with a 110 km/hr operating speed environment. Also, assuming a 90 km/hr operating speed environment and interpolating between desirable minimum and normal maximum values, the 600 m PL on about 7% gradient approximates to about an 800 m PL on flat gradient with about 110 km/h operating speed environment.

Table 8 – AUSTROADS PL Lengths Relative to Operating Speed

Operating Speed (km/h)	PL Length (excluding taper length), (m)			
	Minimum	Desirable Minimum	Normal Maximum	Normal Maximum for Road-Train Routes
50	75	225	325	490
60	100	250	400	600
70	125	325	475	715
80	200	400	650	975
90	275	475	775	1165
100	350	550	950	1425
110	420	620	1070	1605

Note: Desirable minimum values are similar to PO Policy short PL lengths i.e. 600-800 m. Normal maximum values are similar to PO Policy PL lengths up to 7,000 vpd on flat/rolling terrain i.e. 1,200 m. Normal maximum values for road-train routes are similar to Policy PL lengths for 7,000-12,000 vpd on flat/rolling terrain i.e. 1,500 m. Minimum values are considered to be too short for general use on NZ SHs.

The conversion of site 6e to an equivalent PL length on flat gradient to allow for gradient effects, only partly explains the difference between NZ and US values, with observed NZ values being about 39% higher (5.7% cf. 7.9%). As mentioned previously, the upstream signals for site 6e may be partly affecting the results.

However, as both sites 2e and 6e are both on similar gradients the relativity of the upstream-downstream percentage following values is assumed to be retained.

8.6 Predictive Model

From Table 5 of this report, site 2e had a 44% reduction in upstream-downstream percentage following (5.7-3.2)/5.7 = 44%) between the 201-300 and 301-350 veh/h one-way traffic flow ranges (average 325/250 = 30% increase in one-way traffic volumes), This 250 veh/h one-way flow range compares with an upper limit at the 4 sec criteria of 260 veh/h one-way for Site 2e from Cenek and Lester.

From Table 5, Site 6e had a 10% (1- 4.4/4.9 = 10%) reduction in upstream-downstream percentage following between 651-700 veh/h one-way say 675 compared to 701-750 veh/h one-way say 725 (i.e. average 725/675 = 7% increase in one-way traffic volumes). This 675 veh/h one-way upper limit is very close to the 690 veh/h one-way at 4 sec criteria for Site 6e from Cenek and Lester.

Also, for 0% increase in one-way traffic volumes, there will be 0% reduction in upstream-downstream percentage following. Plotting the three points of (0,0), (7,10), (30,44) shows that this relationship is approximately linear.

Therefore, an equation can be used to calculate changes in percentage following for given increases in one-way flow (and hence AADT) (e.g. 8,000 and 10,000 equates to 334 and 418 veh/h one-way so (418-334)/334 = 25% increase in one-way flow and 25x(44/30) = 37% reduction in upstream-downstream percentage following).

8.7 Extrapolation and Interpolation

The US values do not appear to take into account that as one-way flows increase, sites 2e and 6e will start to become ineffective at about 260 veh/h one-way and about 690 veh/h one-way (Cameron, Cenek & Wanty, 2008).

These 260 and 690 veh/h one-way flows are about 6,200 veh/day and 16,500 veh/day for sites 2e (800 m on flat gradient) and 6e (1600 m on flat gradient) respectively. Therefore, the threshold AADTs before plateauing of the passing rate can be interpolated for PL lengths between 800 m (6,200 veh/day) and 1,600 m (16,000 veh/day). PL lengths beyond the 800 m/6000 veh/day and 1600 m/16,000 veh/day intervals can be extraploated. Once the threshold is reached, using the predictive model, the reduction in upstream-downstream percentage following can be calculated for each proportional increase in AADT. The PL length factors have been changed relative to the reduction in upstream-downstream percentage following.

Conclusions Tables 9 and 10 show the modified PL length factors. The workings for generating the modified PL lengths are provided in a working spreadsheet.

It is unlikely that the 400 m PL values (on flat gradient) would be used for new PLs, as a 800 m PL at 110 km/h operating speed is equivalent to about a 575 m PL at 90 km/h operating speed and a 385 m PL at about 70 km/h operating speed.

Using current EEM PL length factors for 800-2,000 m PLs at current 230 veh/h one-way (6,000 veh/day approx), some preliminary adjustment of NZ versus US values for percentage following and travel time & vehicle operating cost savings showed little change between original US and adjusted values for 800-1,200 m PL length at current AADT of 2,000-14,000 veh/day. However, the difference became more marked for the 2,400 m and 3,200 m PLs. Therefore, it would seem appropriate to restrict the factors to PLs of 2,000 m or less. It is unlikely that practitioners would use 2,400-3,200 m PLs at lower one-way flows.

From the proposed spreadsheet of relative frustration cost savings, the 100-200 veh/h values for 1,600 and 2,000 m PLs are higher and appear to be out of step with the pattern of progressively increasing values. Therefore, for TT/VOC benefit and frustration benefit tables, the 2,000-4,000 veh/day values for 1,600-2,000 m PLs could be excluded. It is unlikely that practitioners would use 1,600-2,000 m PLs at traffic flows of 1,000-2,000 veh/day.

9 Slow Vehicle Bay Spreadsheet Analysis Tool

The slow vehicle bay (SVB) spreadsheet analysis tool has been checked to confirm whether any modification is required as a result of the foregoing analysis.

The SVB procedure calculates delays from first principles for an isolated installation, with given upstream and downstream conditions. As a procedure it is somewhat more detailed than the simplified procedure for evaluating individual PLs, which calls for a more detailed analysis (such as

TRARR) if conditions require. Also the PL procedure assumes that a strategic analysis has already been undertaken to determine the spacing of PLs, and the benefit assessment relies on the spacing policy being in effect – in other words the procedure is for an individual PL but not for an isolated PL.

10 Further Investigations

As previously mentioned, NZ surveyed data for percentage following and average travel times has been recorded for five PLs and one SVB from 2 km upstream to about 12 km downstream (Cenek & Lester, 2008).

NZTA's HNO staff have suggested that, although raw data has been recorded, it would have to be extracted and calculated. The resulting percentage following and reductions in journey time could then be used to check (and if required calibrate) PLs length factors to NZ conditions. This work is currently outside the scope for this report.

The data has been collected on a vehicle-by-vehicle basis using pneumatic tubes rather than by number plate recognition. While individual spot speeds at each tube location could be determined, it may be difficult to determine individual and hence travel speeds through the downstream section. Average travel speed through the downstream section is the preferred parameter. Therefore, some preliminary investigation would be required before selecting the speed parameter. Data collection methodology and parameters that match the US data is also a consideration.

Examination of the NZ surveyed measurements for difference in percentage following (immediately upstream-downstream of the PL) would suggest that the performance of PLs on steeper gradients are markedly higher than the same PL length on flat/rolling gradients.

Part of this effect is due to HCV speeds being more affected by steep gradients compared to flat/rolling gradients. The US data relates to terrain on flat and rolling terrain but overseas measurements of rolling terrain are typically flatter than the 3-6% range of gradients used in NZ to generally describe rolling gradient.

Therefore, the relativity of US data may not reflect PLs on steeper gradients of say 5% or more, especially if there are high numbers of HCVs. This possible under-estimation of PL performance on steeper gradients is relevant as many NZ PLs are located to take advantage of the differential speed between HCVs and passenger cars on localised steep gradients.

11 Conclusions

Stage 1 of this project brief concluded that despite the research being 25 years old, from a significantly different vehicle fleet and involving a simulation of hypothetical road section with a limited number of simulation trials, it is nevertheless useful in developing a set of modifying factors for the EEM relative to a base analysis that uses NZ data. It would not be suitable as a source of values rather than relative factors. The tables so developed should be regarded as an interim measure for the EEM until more extensive NZ-based analysis either simulation-based, empirical studies or both, can be undertaken.

Under Stage 2, two sets of modifying factors have been developed (i) based on change in percentage of time spent following to apply to driver frustration benefits and (ii) based on change in the total time delayed to apply to time and VOC benefits.

Tables 9 & 10 provide PL length factors for respectively TT/VOC savings and frustration cost savings.

Table 9 - Modified Factors for Travel Time and Vehicle Operating Cost Benefits

AADT	Passing Lane Length (m, excl tapers)									
(veh/day)	400	600	800	1000	1200	1400	1600#	2000#	2400#	3200#
2000	0.39	0.65	0.91	1.00	1.17	1.15	1.13	1.18	1.16	1.35
4000	0.10	0.60	0.86	1.00	1.19	1.30	1.40	1.55	1.65	1.93
6000	0.05	0.30	0.80	1.00	1.21	1.38	1.54	1.76	1.91	2.25
8000	0.03	0.19	0.50	1.00	1.22	1.43	1.63	1.88	2.08	2.46
10000	0.02	0.13	0.36	0.70	1.24	1.47	1.69	1.97	2.20	2.62
12000	0.02	0.10	0.27	0.53	0.93	1.49	1.73	2.04	2.29	2.74
14000	0.01	0.08	0.21	0.42	0.74	1.51	1.76	2.08	2.35	2.84

Note: # To minimise errors due to extrapolation of data, shaded values to be excluded.

Table 10 - Modified Factors for Frustration Cost Benefits

AADT	Passing Lane Length (m, excl tapers)									
(veh/day)	400	600	800	1000	1200	1400	1600#	2000#	2400#	3200#
2000	0.17	0.52	0.87	1.00	1.13	1.33	1.52	1.71	1.89	1.99
4000	0.04	0.48	0.82	1.00	1.18	1.30	1.41	1.59	1.78	2.10
6000	0.02	0.24	0.80	1.00	1.20	1.29	1.30	1.56	1.75	2.20
8000	0.01	0.15	0.50	1.00	1.21	1.30	1.38	1.58	1.77	2.31
10000	0.01	0.11	0.36	0.70	1.21	1.31	1.40	1.61	1.82	2.44
12000	0.01	0.08	0.27	0.53	0.91	1.32	1.43	1.66	1.89	2.56
14000	0.01	0.06	0.21	0.42	0.72	1.34	1.47	1.71	1.95	2.68

Note: # To minimise errors due to extrapolation of data, shaded values to be excluded.

As an interim measure, it may be better to retain the relativity of the US data, as NZ upstream-downstream measurements are higher. Therefore, retaining the relativity of the US data should provide slightly conservative results. However, there should be the following limitations on use of any modified PL length tables for both TT/VOC savings and frustration cost savings:

- Delete factors for the longer PLs (i.e. more than 2000 m). (Currently, the EEM table only caters for up to 2000 m anyway and any relative error would be restricted to factors for 2000 m PL as 1600 m has been calibrated. Delete values for 1.6 -2.0 km PLs from 0-4,000 vpd, as these traffic volumes were below volumes recorded at the US calibration site for the 1.6 km PL.
- For PL lengths between the factors shown in the Tables 9 & 10, interpolation is allowed. For example, TT & VOC savings for a 700 m PL at current 6,000 vpd would be (0.80+0.24)/2 = 0.52.
- Frustration savings benefits are based on isolated PLs but will need to take into account infilling between existing PLs, which will provide a new PL with shorter spacing, as well as shortening the spacing of the existing upstream PL.
- As the PL length factors vary with AADT, the PL performance will also vary. It is proposed that a weighted average PL length factor is used relative to AADT over the 30 year project life. A similar weighted average PL Length factor would be calculated for PL extensions.
- Allow for differences in PL gradient by relating PL length to the current operating speed. (AUSTROADS Rural Road Design has tables of PL length relative to operating speed).

- Where possible, PL lengths should be avoided if there will be a reduced PL length factor during the 30 year analysis period of the PL. While it may be economical to provide a shorter PL length at reduced efficiency, the level of service at these higher AADTs will be reduced. The PL lengths suggested within the Passing & Overtaking Policy layout table will provide guidance on the choice of PL length to ensure an adequate level of service over the analysis period.

Raw data on percentage following and average travel speed has been collected on 5 PLs and 1 slow vehicle bay. Processing of this data may be beneficial in establishing surveyed measurements at various locations from 2 km upstream to about 12 km downstream of the surveyed passing facilities.

The resulting values of percentage following and reductions in journey time could then be used to calibrate computer simulations of downstream PL benefits under typical NZ road geometrics for flat, rolling and mountainous gradients. Some preliminary investigation may be required into whether the data collection would allow individual or average travel times through the SH sections to be calculated, as opposed to spot speed measurements at pneumatic tube locations.

12 Recommendations for Future Action

The new tables of modifying factors should only be regarded as a stop-gap measure until such time as a more detailed assessment can be made.

Extension of the tables to different PL spacings might be attempted by digitizing the graphs in Figure 8 of Harwood and St John, then fitting families of curves – probably a decay curve over the PL length and then a reverse curve with asymptote to a notional maximum level of percentage vehicles platooned. The resulting areas under the graphs could then be integrated over various downstream distances to give the total percentage of vehicles delayed for different PL spacings. The upstream platooning could then be adjusted to match the platooning at the end of the PL spacing. This would give a better estimate of the dual effect of PL length and PL spacing on the reduction in percentage of delay time in platoons. However, it would still be reliant on somewhat unknown geometric characteristics of the simulation section, so would not be readily generalised or calibrated to NZ conditions. Also there is no similar way of obtaining the total delay time for factoring time and VOCs.

Alternatively, the original analysis used to create the PL simplified procedures could be re-run to cover a wider range of PL lengths, traffic volumes and PL spacings. However, as this was a very time consuming process, a better approach might be to create a set of simulation sections based on an analysis of the geometry in the 1/3 sample of the NZ state highway network, and use this as a testbed. A more ambitious project again would be to develop the same testbed in TRARR, which would allow a more complex mix of traffic, but at relatively high cost. Possibly, some selected TRARR runs could be used to validate and better calibrate both the PL length factors and downstream benefit graphs within the EEM simplified analysis.

These selected TRARR runs would benefit from being verified against survey data obtained as part of Cenek and Lester's work but some preliminary investigation would be required to determine if average travel speeds can be determined from the data, as a preferred parameter to spot speeds at various downstream locations.

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