CAMCOMP

PARTNERS PTY. LTD. (ABN 38 815 586 279)

Report to New Zealand Transport Agency

Economic Analysis of Optimum Speeds on Rural State Highways in New Zealand

Max Cameron, PhD

Written October 2012
Published March 2022

ISBN 978-1-99-004459-5

Waka Kotahi NZ Transport Agency
Private Bag 6995, Wellington 6141, New Zealand
Telephone 64 4 894 5400; facsimile 64 4 894 6100
NZTAresearch@nzta.govt.nz
www.nzta.govt.nz

Cameron, M. H. (2022). *Economic analysis of optimum speeds on rural state highways in New Zealand*. Waka Kotahi NZ Transport Agency.

Camcomp Partners Pty Ltd, Melbourne, Australia, email: camcomp@webmin.com

Camcomp Partners Pty Ltd was contracted by NZ Transport Agency in 2012 to carry out this research

Keywords: road, safe, safety, speed, optimum, time, travel, value, air pollution, vehicle operating cost

Contents

EXECUTIVE SUMMARY

The objective of this project was to calculate the optimum speeds for six categories of New Zealand rural State Highways:

1. Motorways/Expressways (divided four-lane) roads (435 km with 26,611 vehicles/day)
2. High Volume National Strategic (undivided) roads (371 km with 12,817 vehicles/day)
3. Straight National & Regional Strategic roads (2,825 km with 4,764 vehicles/day)
4. Winding National & Regional Strategic roads (343 km with 4,478 vehicles/day)
5. Straight Regional Connector & Distributor roads (4,920 km with 1,829 vehicles/day)
6. Winding Regional Connector & Distributor roads (1,118 km with 1,850 vehicles/day).

The optimum speed for a class of road was defined as one which minimises the total social costs of the impacts of speed. As such, an optimum speed limit is one that provides maximum benefit from reduced travel times and minimises the costs of road trauma, environmental emissions and vehicle operating costs. However, noise pollution could not be considered.

The economic evaluation considered the effect of cruise speeds of each vehicle type (passenger cars and light, medium and heavy commercial vehicles) ranging from 70 to 130 km/h on:

- Crash frequencies and costs
- Travel time costs, including costs for the freight industry
- Vehicle operating costs
- Air pollution costs.

The effects of changes in speed on crashes at each injury severity level were estimated using well-established relationships for rural roads originated in Sweden by Nilsson and recalibrated by recent meta-analysis of extensive evaluations of speed changes. Travel time was considered inversely related to cruise speed, but was adjusted for the number of stopping points and decelerations for slow curves using the additional time per speed change cycle given in NZTA's Economic Evaluation Manual (EEM). Vehicle operating cost (VOC) functions related to speed were obtained from EEM for each vehicle type and road gradient. Additional VOC per speed change cycle for each stop and deceleration for curves was also obtained from EEM. Carbon dioxide emissions were estimated from VOC and other air pollution emissions from procedures in EEM. Emissions other than carbon dioxide were adjusted for stops and curves using a cruder method than that available for travel time and VOC in EEM, but these emissions were valued at only 1% of their urban cost because of their lower impact in rural areas.

Each of the costs of crashes, travel time, vehicle operations and carbon dioxide emissions on each category of rural State Highway for each vehicle type were valued using the unit costs in EEM and updated to 2009 values by the update factors provided. For each cruise speed, the total economic cost was aggregated and the speed that minimised the total cost for all light vehicles, within the range 70 to 130 km/h, was found. The optimum speed that minimised the total cost for all heavy vehicles was found in the same way. The estimated optimum speeds, in comparison with current cruise speeds provided by NZTA, are shown in Table I.

Table I: Current cruise speeds by vehicle type and estimated optimum speeds (not less than 70 km/h).

	Current cruise speeds on straight sections of rural highways (km/h)				Optimum cruise speeds (km/h)	
Road Category	Cars & light commercial vehicles (LCV)	Medium commercial vehicles (MCV)	Heavy commercial vehicles I (HCV I)	Heavy commercial vehicles II (HCV II)	Light vehicles (Cars & LCVs)	Heavy vehicles (MCVs & HCVs)
1. Motorways/Expressways (divided four-lane) roads	99.1	90.7	92.5	91.5	105	80
2. High Volume National Strategic roads	93.9	86.1	87.7	86.9	85	70
3. Straight National & Regional Strategic roads	95.8	87.8	89.5	88.6	80	70
4. Winding National & Regional Strategic roads	83.6	77.2	78.4	77.8	75	70
5. Straight Regional Connectors & Distributors	95.7	87.7	89.4	88.5	80	70
6. Winding Regional Connectors & Distributors	79.7	73.9	74.9	74.4	70	70

The impacts if light and heavy vehicles changed from travelling at their current cruise speeds to their optimum speeds were calculated for each road category. The total impact of such a change, aggregated across all categories of rural State Highway, is shown in Tables II and III.

Table II: Physical impact if all vehicles changed to travelling at their optimum speed, compared to travelling at their current speeds.

Type of impact		**Before**	**After**	**Change**	
Total travel time on link, hours/day		466,877	515,889	49,012	10.5 %
Number of Casualty Crashes per year		8,728	7,240	-1,489	-17.1%
Emissions, t/year	Carbon monoxide CO	115,307	98,560	-16,747	-14.5 %
	Hydrocarbons HC	7,129	6,168	-961	-13.5 %
	Oxides of nitrogen NO_x	37,095	31,169	-5,926	-16.0 %
	Particles PM	3,542	2,908	-633	-17.9 %
	Carbon dioxide CO_2	8,027,707	7,462,776	-564,931	-7.0 %

Table III: Economic impact if all vehicles changed to travelling at their optimum speed.

$'000/year	**Before**	**After**	**Change**	
Vehicle operating costs	6,617,280	6,202,356	-414,924	-6.3 %
Time costs	4,661,854	5,192,801	530,947	11.4 %
Crash costs	1,484,548	911,946	-572,602	-38.6%
Air pollution costs	335,556	310,396	-25,160	-7.5 %
Total	**13,099,238**	**12,617,499**		
Change			**-481,739**	**-3.7 %**

While crashes on motorways/expressways may increase due to an increase in car and LCV speeds, the overall reduction in casualty crashes represents an annual saving of 90 fatal crashes (approximately 60% of the fatal crashes on rural State Highways), 334 serious injury crashes, and 1,065 minor injury crashes. When these savings in road trauma were valued using the unit costs of crashes in EEM related to their injury severity, it was estimated that there would be 39% reduction in crash costs on rural highways (Table III). The overall economic impact if all vehicles travelled at their optimum speeds was estimated to be a saving of $482 million per annum in total social costs or 3.7% reduction in the estimated $13.1 billion annual cost of rural State Highway travel in New Zealand.

Sensitivity analysis

The analysis described in this report included many assumptions, constraints and cost valuations. Three of these were examined to test the sensitivity of the estimates of optimum speed to the following variations on the economic analysis:

1. Cruise speeds below 70 km/h for each vehicle type
2. Increased valuation of travel time costs
3. Ignoring under-reporting of non-fatal reported crashes.

The results of the sensitivity analysis are shown in Table IV.

Table IV: Estimated optimum speeds resulting from variations in the economic analysis.

	Optimum cruise speeds without 70 km/h lower limit		Optimum cruise speeds with travel time costs per hour doubled		Optimum cruise speeds based on reported crashes (ignoring under-reporting)	
Road Category	Light vehicles (Cars & LCVs)	Heavy vehicles (MCVs & HCVs)	Light vehicles (Cars & LCVs)	Heavy vehicles (MCVs & HCVs)	Light vehicles (Cars & LCVs)	Heavy vehicles (MCVs & HCVs)
1. Motorways/ Expressways (divided)	105	80	130	95	110	80
2. High Volume National Strategic roads	85	70	95	85	90	75
3. Straight National & Regional Strategic roads	80	70	95	80	85	70
4. Winding National & Regional Strategic roads	75	65	85	75	80	65
5. Straight Regional Connectors & Distributors	80	70	90	75	80	70
6. Winding Regional Connectors & Distributors	65	55	75	65	70	55

Conclusions

The findings of this report depend on the functional relationships between speed and road trauma, travel time, air pollution emissions and vehicle operating costs, the assumptions made, and the input parameters. The sensitivity of the findings to variations in these factors has been tested only to a limited extent. Within the limits of the assumptions made and the data available, the following conclusions were reached.

1. The optimum speeds on Category 1 Motorways/Expressways (divided four-lane) roads would be 105 km/h for cars and light commercial vehicles and 80 km/h for trucks[1]. On other categories of (undivided) rural highways, the optimum speeds would be at most 70 km/h for trucks, but the optimum speed for cars and light commercial vehicles ranges from 85 km/h down to 65 km/h depending on the quality of the road and whether through a winding road environment.

2. Rationalisation of speed limits applicable to each class of rural highway and for each type of vehicle, making the limits consistent with the optimum speed in each case, has the potential to reduce casualty crashes and crash costs substantially. Although travel times and costs would increase, there would be a reduction in the total social costs on rural highways when all the benefits of reduced road trauma, air pollution emissions and vehicle operating costs from reduced speeds are considered.

3. The results suggest that differential speed limits would be appropriate in each category of rural highway apart from those through winding road environments (where, however, substantially reduced general speed limits for all vehicle types are appropriate). If differential speed limits were to be applied on some undivided rural highways, then attention should be given to providing adequate overtaking opportunities.

[1] This analysis was based on 435 km of Motorways primarily centred around Auckland and Wellington and divided four-lane Expressway roads primarily located in north Waikato. It is important to note that this finding is based on "free-flow" speeds where traffic volumes allow. Higher traffic volumes around major centres would be unlikely to sustain such high speeds, particularly in peak periods.

ECONOMIC ANALYSIS OF OPTIMUM SPEEDS ON RURAL HIGHWAYS IN NEW ZEALAND

1. INTRODUCTION

The optimum speed for a class of road was defined as one which minimises the total social costs of the impacts of speed. As such, an optimum speed limit is one that provides maximum benefit from reduced travel times and minimises the costs of road trauma, environmental emissions and vehicle operating costs.

The objective of this project was to calculate the optimum speeds for six categories of New Zealand rural State Highways:

1. Motorways/Expressways (divided four-lane) roads (435 km with 26,611 vehicles/day)
2. High Volume National Strategic (undivided) roads (371 km with 12,817 vehicles/day)
3. Straight National & Regional Strategic roads (2,825 km with 4,764 vehicles/day)
4. Winding National & Regional Strategic roads (343 km with 4,478 vehicles/day)
5. Straight Regional Connector & Distributor roads (4,920 km with 1,829 vehicles/day)
6. Winding Regional Connector & Distributor roads (1,118 km with 1,850 vehicles/day).

The system-wide impacts if cars and trucks were to travel at their optimum speeds, as a basis for setting speed limits in each road environment, are also calculated. It should be noted that optimum speeds are not necessarily Safe System speeds (NZ MoT 2009).

The economic evaluation considered the effect of a range of cruise speeds of each vehicle type (passenger cars and light, medium and heavy commercial vehicles) on:

- Travel time costs, including costs for the freight industry;
- Vehicle operating costs;
- Crash costs; and
- Air pollution costs.

Previous research in Europe suggested that there is sufficient knowledge relating road trauma, vehicle operating costs, air pollution emissions, noise and travel time to vehicle speeds to indicate that the project was feasible (Nilsson 1984; Andersson et al 1991; Peters et al 1996; Rietveld et al 1996; Carlsson 1997; Toivanen and Kallberg 1998; Elvik 1999, 2002). Also, subsequent Australian research has built on the European experience and calibrated the relationships with vehicle speeds using Australian data (Cameron 2000, 2001, 2003, 2004, 2011, 2012).

2. PREVIOUS RESEARCH ON IMPACTS OF SPEEDS

Much of the previous research was concerned with estimating the optimum speed of vehicle travel on various classes of road in different road environments. The optimum speed is defined as one which balances the social costs and benefits of increased travel time with decreased road trauma, vehicle operating costs, emissions, and other costs.

2.1 EUROPEAN RESEARCH

Nilsson (1984) reported separate relationships between the increase in the numbers of killed, seriously injured, and slightly injured car occupants, and the increase in the median speed relative to baseline conditions. He built on these relationships to estimate the total injury cost for car occupants per million vehicle kilometres travelled as a function of median speed, for each of six rural road environments in Sweden.

Some roads had much higher median speeds than would be expected if they had the same ‘accepted’ balance between speed and injury cost rate which was displayed on other roads. Nilsson argued that speeds on these roads would need to be reduced (in the order of 5-10 km/h) if the same balance of speed and injury costs were to be achieved on all roads. While Nilsson’s proposals may not have achieved the optimum balance, they were aimed in this direction.

Andersson et al (1991) calculated optimal speeds on different classes of Swedish roads on the basis of socio-economic costs. The optimal speed was defined as the speed where the sum of crash costs (injuries and material damage), vehicle operating costs, and travel time costs was lowest. The prices or values used were the same as those normally used in official transport economic calculations in Sweden.

They found that the optimal speeds on three types of urban roads, presently speed-zoned with 50 km/h limits, was in the range 47-58 km/h. However, in the rural road environments, the optimal speeds were considerably lower than the current mean speeds and the speed limits.

Plowden and Hillman (1996) calculated optimal speed limits for UK main roads, both outside and inside towns. The calculations took into account the speed-related impacts on and economic values of fuel, other vehicle operating costs, travel time and crashes. The results were considered to be the upper boundaries of the speed limits because all the impacts left out of the calculations were negative, and increase with speed (e.g. noise pollution). The calculations were made with and without the assumption of an effect whereby reduced speed limits influence how much road users travel.

For motorways and ‘A’ roads outside towns, in general they found that optimal speed limits were up to 15 mph lower than existing limits, depending on the road class and assumptions on fuel taxation. Their analysis of urban roads had greater difficulties determining the effects of speed changes, but they concluded that the urban speed limit should normally be 20 mph (32 km/h). However, it appears that some of their assumptions may have been extreme, so this figure could be viewed as a lower limit for optimal speeds in urban areas. They made a number of suggestions for further work to refine this area.

Rietveld et al (1996) calculated the socially optimal speed for passenger cars on different roads types in the Netherlands, with and without the assumption that total travel is independent of changes in speed. The calculations made a distinction between fatal and other serious crashes, and also included the speed-related impacts on travel time, energy use, and CO_2 and NO_X emissions. Further information on their methods and data is given by Peeters et al (1996) and Coesel and Rietveld (1998).

The researchers had to rely on general estimates of the elasticity between travelling time and vehicle travel when estimating the speed-related impacts. They noted that a full network model would have been necessary to provide a more realistic estimate of the effects of speed changes on travel demand. They also stated that their analysis was incomplete because they were not able to consider the effects on noise pollution and costs.

Rietveld et al noted that vehicles seldom travel at constant speed and that actual average speeds are considerably lower than speed limits and desired speeds, especially in urban areas. On urban roads with a 50 km/h limit, they found that the average speed was 38 km/h on major urban through roads and 27 km/h on other urban roads. The average speed was 15 km/h in residential streets, which have a 30 km/h limit. They also found that the optimal speed on the urban roads/streets was close to (or a little less than) the average speed in each case, whereas on the higher speed limited rural roads the optimal speeds were considerably less than the corresponding averages. In the urban areas in the Netherlands, it appears that desired speed behaviour is generally consistent with the current speed limits and produces average speeds which are close to socially optimal.

Elvik (1999) undertook a similar analysis to calculate the optimal speed in urban areas in Norway, considering in addition the speed-related impacts on noise pollution and feelings of insecurity towards children. He found that the optimal speed on urban main roads was 50 km/h, on collector roads it was 40 km/h, and on residential access roads it was 30 km/h.

Carlsson (1997) calculated the optimum speeds of passenger cars on different types of rural roads in Sweden. The speed-related effects on fatalities, serious injuries, slight injuries, property damage, travel time, fuel consumption, tyre wear, and CO_2 , NO_X and HC emissions were all included. He found that the present travel speeds in Sweden were 15-25 km/h higher than the optimum speed for each type of road.

Kallberg and Toivanen (1998) described a framework for assessing the impacts of speed, developed as part of the European project MASTER (Managing Speeds of Traffic on European Roads). While they did not use this to calculate optimum speeds, the framework was a valuable basis for the project described here. The framework aimed to provide a comprehensive coverage of all the impacts, both direct and indirect, and quantifiable and non-quantifiable.

Kallberg and Toivanen drew an important distinction between the impacts of speed at the level of the individual road section or link, viewed in isolation, and at the level of the transport network. It is possible that changes in speeds or speed limits on individual links can have impacts on perceived accessibility, transport modal split, and broader socio-economic impacts, all of which can have feedback effects on travel speeds. They also noted that speed management can have objectives related to *efficiency* (where socio-economic cost-benefit analysis is an important tool) and *equity* (where the distribution of the costs and benefits of speed needs to be considered). Speeds which are desirable from an efficiency point-of-view may not be acceptable because of real or perceived inequities to some parts of society. However, the inequities are usually difficult to quantify.

The MASTER project developed a computer spreadsheet to allow all the impacts of a change in speed management policy to be recorded, and analysed where appropriate. A copy of the output from the spreadsheet (without data entered) is given in Appendix A to illustrate its structure. Kallberg and Toivnanen (1998) gave a detailed description, and illustrated its use by applying it to speed policy issues in Finland, Hungary and Portugal. The spreadsheet provided a useful computational basis (with modifications) for the calculation of the impacts of different travel speeds for the project described here (Appendix B onwards).

2.2 AUSTRALIAN RESEARCH

Cameron (2000, 2001) used the MASTER framework to estimate the optimum speed on urban residential streets in Australia. He found that the optimum speed depended on the method used to value road trauma. When the 'human capital' valuations of road trauma costs (BTE 2000) were used, the analysis suggested that the optimum speed on residential streets is 55 km/h. When the analysis was repeated making use of road trauma costs valued by the 'willingness to pay' approach (BTCE 1997), the analysis suggested that the optimum speed on residential streets is 50 km/h. Noise costs in urban areas could not be valued in the analysis, but the travel time on residential streets was (using the value per hour for private car travel, since most travel in residential areas is for non-business purposes).

Cameron (2003, 2004, 2011) also used the MASTER framework (modified) to aggregate the economic costs and benefits of changes to speed limits on rural roads in Australia. The key modification was that the effects of speed on road trauma levels were calculated using relationships linking changes in average free speed on rural roads with changes in crashes at each severity level, developed in Sweden by Nilsson (1981, 2004). Road trauma was valued by the then official Australian-government 'human capital' unit costs related to the injury severity of crash outcomes (BTE 2000). The unit cost of a fatal crash was valued at A$1.74 million in year 2000 dollars. Subsequent official government publications have valued the unit cost of a fatal crash at A$2.67 million in year 2006 (BITRE 2009).

Net costs and benefits were estimated over a range of mean travel speeds (80 to 130 km/h) for the following road classes:

- freeway standard rural roads
- other divided rural roads (not of freeway standard)
- two-lane undivided rural roads (with and without shoulder sealing).

Vehicle operating costs for cars, light commercial vehicles and rigid and articulated trucks were based on Austroads published models linking these costs with speed (Thoresen, Roper and Michel 2003). Emission rates of air pollutants of each type were derived from research conducted as part of the MASTER project for the European Commission (Robertson, Ward and Marsden 1998, Kallberg and Toivanen 1998). Increased fuel consumption and emission rates associated with deceleration from cruise speeds for sharp curves (and occasional stops) on undivided rural roads, and then acceleration again, were estimated from mathematical models calibrated for this purpose in the USA (Ding 2000). Air pollution cost estimates were provided by Cosgrove (1994). The analysis also provided estimates of average speeds over 100 km sections of curvy undivided roads. Otherwise it was assumed that travel time = link length / speed of traffic flow. This was considered to be a reasonable assumption on rural roads where traffic congestion, and hence constrained speeds, are a rarity. Travel time was valued by Austroads estimates of time costs reflecting the vehicle type and trip purposes (Thoresen, Roper and Michel 2003).

An update of that analysis (Cameron 2012) used recent 'willingness to pay' estimates of the values assigned to preventing person casualties (NSW Roads and Traffic Authority 2008). The value assigned to each fatal crash in the update was A$8.03 million in 2011. Table 1 shows the difference in optimum speeds in each rural road environment when crashes at each level of injury severity (fatal, serious injury and minor injury) are valued by 'willingness to pay' unit costs compared with 'human capital' unit costs (Cameron 2012 and 2011, respectively). The method of valuing the changes in crash frequencies at each level of cruise speed on rural roads was the principal difference between to two studies. New vehicle operating cost models and unit costs of travel time and air pollution updated by Perovic et al (2008) for Austroads had little effect on the estimation of optimum speeds.

Table 1: Estimated optimum speeds using 'willingness to pay' (WTP) values of road trauma (Cameron 2012) and using 'human capital' unit costs (Cameron 2011)

	Current cruise speeds (speed limits)		**Optimum speeds based on WTP values**		**Optimum speeds based on human capital costs**	
Road environment	Cars & LCVs	Trucks	Cars & LCVs	Trucks	Cars & LCVs	Trucks
Rural freeways	110	100	110	95	125	100
Rural divided roads	110	100	95	90	120	95
Standard sealed two-way undivided	100	100	90	85	100	85
- curvy roads with crossroads and towns	100	100	85	85	85	80[a]
Shoulder-sealed two-way undivided	100	100	90	90	105	90
- curvy roads with crossroads and towns	100	100	85	85	90	85

[a] This estimate is less than 85 km/h because of the earlier vehicle operating cost model used by Cameron (2011) compared with that used by Cameron (2012), resulting in lower estimated cost at low speeds

3. METHOD OF THIS STUDY

3.1 CURRENT SPEEDS ON RURAL HIGHWAYS

The current mean free speeds on straight roads in each road category in New Zealand were provided by the New Zealand Transport Agency (NZTA) and are shown in Table 2. These speeds formed the basis ('before' speeds) to examine the effects on road trauma, travel time, emissions and vehicle operating costs of each change in cruise speed from current conditions. For each vehicle type and road category, cruise speeds from 70 km/h to 130 km/h in steps of 5 km/h were analysed.

3.2 EFFECT OF SPEED ON ROAD TRAUMA

3.2.1 Nilsson's relationships between speed and crashes of different injury severity

The effects of speed on road trauma levels were calculated using relationships linking changes in average free speed with changes in numbers of fatal, serious injury and minor injury crashes, as follows:

$$\mathbf{n_A = (v_A/v_B)^p * n_B}$$

where $\mathbf{n_A}$ = number of crashes after the speed change

$\mathbf{n_B}$ = number of crashes before the speed change

$\mathbf{v_A}$ = mean or median free speed after

$\mathbf{v_B}$ = mean or median free speed before

$\mathbf{p}$ = estimated exponent depending on the injury severity of the crashes.

Relationships of this form were originally developed by Nilsson (1981) based on research linking changes in median free speeds with changes in crash frequencies at various injury severities, as a result of many changes in rural speed limits in Sweden during 1967-1972.

Table 2: Estimated mean free speeds by vehicle type and road category (km/h)

Road Category	Passenger cars	Light commercial vehicles (LCV)	Medium commercial vehicles (MCV)	Heavy commercial vehicles I (HCV I)	Heavy commercial vehicles II (HCV II)
1. Motorways/ Expressways (divided)	99.1	99.1	90.7	92.5	91.5
2. High Volume National Strategic roads	93.9	93.9	86.1	87.7	86.9
3. Straight National & Regional Strategic roads	95.8	95.8	87.8	89.5	88.6
4. Winding National & Regional Strategic roads	83.6	83.6	77.2	78.4	77.8
5. Straight Regional Connectors & Distributors	95.7	95.7	87.7	89.4	88.5
6. Winding Regional Connectors & Distributors	79.7	79.7	73.9	74.9	74.4

3.2.2 Meta-analysis to update Nilsson's relationships

Meta-analysis of a large number of subsequent studies of road trauma changes associated with speed limit changes has since been conducted (Elvik et al 2004; Elvik 2009; Cameron and Elvik 2010). The analysis confirmed Nilsson's relationships on rural roads and freeways, but found that the relationships were weaker or non-existent on urban roads. The final exponent estimates (**p**) for fatal crashes (4.1), serious injury crashes (2.6) and slight injury crashes (1.1) on rural roads and freeways (Cameron and Elvik 2010) were used here.

3.2.3 Current crash rates on rural highways

The casualty crash rate per 100 million vehicle-km on each category of road during 2006-2010, adjusted for under-reporting of the non-fatal crashes, provided the base road trauma situation associated with the current mean free speeds (Table 3).

An adjustment for under-reporting of crashes in Australia has not been considered in Austroads reports (Thoresen et al 2003, Perovic et al 2008) and the casualty crash rates per 100 million vehicle-km used by Cameron (2003, 2004, 2011, 2012) were based on reported casualty crashes and their severity distribution to produce the results in Table 1. EEM Table A6.20(a) requires that non-fatal reported crashes on motorways (both serious and minor injury crashes) be increased by 90% to estimate actual numbers, and that on other 80 or 100 km/h speed limit roads the serious and minor injury crashes be increased by factors of 1.9 and 4.5, respectively. The influence of these adjustments for the under-reporting of crashes in New Zealand on any comparison of the results in this report with those from Australia will be discussed in Section 7.

Table 3: Casualty crash rates and crash injury severity profiles (2006-2010)

Road Category	Casualty crash rate per 100 M vehicle-km	Fatal	Serious injury	Minor injury
1. Motorways/ Expressways (divided)	23.6	0.7%	8.2%	91.1%
2. High Volume National Strategic roads	47.7	2.0%	11.7%	86.3%
3. Straight National & Regional Strategic roads	66.8	1.9%	11.7%	86.4%
4. Winding National & Regional Strategic roads	58.9	1.3%	13.3%	85.5%
5. Straight Regional Connectors & Distributors	78.6	1.8%	12.1%	86.1%
6. Winding Regional Connectors & Distributors	89.0	1.7%	13.3%	85.0%

The estimated annual casualty crash frequency involving each vehicle type was sub-divided by injury outcome (fatal, serious or minor injury crashes) based on crash injury severity data for 2001-2010 provided by NZTA (Table 4).

Table 4: Injury severity profile of casualty crashes by vehicle type involved (2001-2010)

Road Type	Vehicle Type	Fatal (%)	Serious injury (%)	Minor injury (%)
Motorways	Passenger car	0.44	6.27	93.29
	Van or Utility (LCV)	0.64	8.62	90.74
	Truck (MCV or HCV)	1.09	12.31	86.60
Other State Highways (open road)	Passenger car	2.06	12.05	85.89
	Van or Utility (LCV)	2.20	13.24	84.55
	Truck (MCV or HCV)	4.15	14.46	81.39

Injury severity in crashes on motorways was substantially less than that on other rural highways, reflecting the superior design and more-forgiving roadside environment on that class of road.

3.2.4 Valuation of changes in road trauma due to changes in speed

Modified Nilsson (1981) relationships, as described in Section 3.2.2, were used to estimate the annual crash frequency and injury severity, by vehicle type, for each specific speed.

The annual crash numbers were weighted by the unit crash costs, by injury severity, on New Zealand 100 km/h speed limit roads, given in NZTA's (2010) Economic Evaluation Manual (EEM). The unit costs updated from 2006 values to 2009 were:

- Fatal crashes NZ$ 4.332 million
- Serious injury crashes NZ$ 461,700
- Minor injury crashes NZ$ 27,400

3.3 EFFECT OF SPEED ON TRAVEL TIME

On straight rural roads without stops it can generally be assumed that travel time = link length / free speed of traffic flow (cruise speed). However, all categories of New Zealand rural highways had some stop points and a number of curves of different radii. The curve negotiation speeds provided by NZTA, based on the nominal radius of each curve category, are shown in Table 5. NZTA also provided information on the numbers of stop points and curves of each radius on each category of rural highway. The density of these stops and curves per 100 kilometre of road is shown in Table 6.

Table 5: Estimated negotiation speeds by vehicle type and curve radius category

Maximum radius	Minimum radius	Nominal radius	Cars and LCVs (km/h)	MCV (km/h)	HCVI (km/h)	HCVII (km/h)
400m	200m	300m	89	81.9	83.3	82.6
200m	100m	150m	79	73.3	74.3	73.8
100m	20m	50m	49	47.4	47.3	47.4

Table 6: Stops and curves per 100 km in each road category

		Curve radius category		
Road Category	Stops	200-400m	100-200m	20-100m
1. Motorways/ Expressways (divided)	2.1	14.0	1.6	1.8
2. High Volume National Strategic roads	1.9	61.2	8.6	7.0
3. Straight National & Regional Strategic roads	0.6	70.2	36.7	14.6
4. Winding National & Regional Strategic roads	0.9	84.1	56.3	49.0
5. Straight Regional Connectors & Distributors	1.0	85.8	52.4	33.6
6. Winding Regional Connectors & Distributors	0.4	107.5	126.3	117.1

3.3.1 Additional travel time due to curves and stops

The additional travel time per curve due to the reduction in vehicle speed from its cruise speed to the negotiation speed (if necessary), and back to cruise speed, has been calculated for each vehicle type in EEM Tables A5.7 (NZTA 2010).

Formulae derived from these tables were used to calculate the additional time per curve (and per stop, using a negotiation speed of zero), then summed across all curves and stops in each road category, and then added to the travel time calculated as if vehicles had cruised throughout the full road length.

The formulae were developed for NZTA by MWH New Zealand Ltd by fitting high order polynomials to the data in EEM Tables A5.7 as functions of the initial entry speeds and negotiation speeds ranging from 0 to 120 km/h. Separate formulae were provided for each of the five vehicle types analysed in this study. MWH New Zealand indicated that the formulae were accurate to within 0.1 seconds of the additional travel time per speed change cycle (i.e. time required for the vehicle to decelerate from the initial cruise speed to the negotiation speed and accelerate back again to the cruise speed) in the EEM tables (for example, Table A5.24 for passenger cars, shown below) and could be interpolated between the tabulated speeds.

Table A5.24: Passenger car additional travel time due to speed change cycles (seconds/speed cycle)

Initial speed (km/h)	Additional travel time in seconds/speed cycle by final speed																						
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
5	2.2																							
10	4.1	1.1																						
15	5.8	2.8	0.8																					
20	7.4	4.4	2.1	0.6																				
25	8.9	6.0	3.6	1.7	0.5																			
30	10.4	7.5	5.1	3.0	1.5	0.4																		
35	11.8	9.0	6.5	4.4	2.6	1.3	0.4																	
40	13.1	10.4	8.0	5.8	3.9	2.3	1.1	0.3																
45	13.7	11.4	9.2	7.2	5.2	3.5	2.1	1.0	0.3															
50	14.3	12.1	10.0	8.1	6.3	4.7	3.2	1.9	0.9	0.3														
55	14.9	12.8	10.8	8.9	7.2	5.6	4.2	2.9	1.8	0.9	0.2													
60	15.4	13.4	11.5	9.7	8.1	6.5	5.1	3.8	2.6	1.7	0.8	0.2												
65	15.9	14.0	12.2	10.5	8.9	7.4	5.9	4.6	3.5	2.4	1.5	0.8	0.2											
70	16.4	14.6	12.9	11.2	9.6	8.2	6.8	5.5	4.3	3.2	2.2	1.4	0.7	0.2										
75	16.9	15.2	13.5	11.9	10.4	8.9	7.5	6.2	5.0	3.9	2.9	2.0	1.3	0.7	0.2									
80	17.4	15.7	14.1	12.5	11.1	9.6	8.3	7.0	5.8	4.7	3.7	2.7	1.9	1.2	0.6	0.2								
85	17.8	16.2	14.7	13.2	11.7	10.3	9.0	7.7	6.6	5.4	4.4	3.4	2.5	1.8	1.1	0.6	0.2							
90	18.3	16.7	15.2	13.8	12.4	11.0	9.7	8.5	7.3	6.2	5.1	4.1	3.2	2.4	1.7	1.0	0.5	0.2						
95	18.8	17.2	15.8	14.4	13.0	11.7	10.4	9.1	8.0	6.9	5.8	4.8	3.9	3.0	2.3	1.6	1.0	0.5	0.2					
100	19.2	17.7	16.3	14.9	13.6	12.3	11.0	9.8	8.7	7.5	6.5	5.5	4.6	3.7	2.9	2.1	1.5	0.9	0.5	0.2				
105	19.6	18.2	16.8	15.5	14.2	12.9	11.7	10.5	9.3	8.2	7.2	6.2	5.2	4.3	3.5	2.7	2.0	1.4	0.9	0.5	0.1			
110	20.1	18.7	17.3	16.0	14.7	13.5	12.3	11.1	10.0	8.9	7.8	6.8	5.9	5.0	4.1	3.3	2.6	1.9	1.3	0.8	0.4	0.1		
115	20.5	19.1	17.8	16.5	15.3	14.0	12.9	11.7	10.6	9.5	8.5	7.5	6.5	5.6	4.7	3.9	3.2	2.5	1.8	1.3	0.8	0.4	0.1	
120	20.9	19.6	18.3	17.0	15.8	14.6	13.4	12.3	11.2	10.1	9.1	8.1	7.1	6.2	5.4	4.5	3.8	3.0	2.4	1.8	1.2	0.8	0.4	0.1

Source: Economic Evaluation Manual (Volume 1) (NZTA 2010)

3.3.2 Valuation of travel time

Travel time was valued by NZTA's (2010) estimates of time costs reflecting the vehicle type and trip purposes in EEM Tables A4.1 and A4.2, and vehicle occupancy in Table A2.4. The unit costs per hour were updated from 2002 values to 2009 using a factor of 1.22 given in EEM Table A12.3.

Table A4.1: Values for vehicle occupant transport user time in $/h (all road categories; all time periods – July 2002)

Vehicle occupant	Work travel purpose	Commuting to/ from work	Other non-work travel purposes
Base values of time for uncongested traffic ($/h)			
Car (motorcycle driver)	23.85	7.80	6.90
Car (motorcycle passenger)	21.70	5.85	5.20
Light commercial driver	23.45	7.80	6.90
Light commercial passenger	21.70	5.85	5.20
Medium/heavy commercial driver	20.10	7.80	6.90
Medium/heavy commercial passenger	20.10	5.85	5.20

Source: Economic Evaluation Manual (Volume 1) (NZTA 2010)

Table A4.2: Base values for vehicle and freight time in $/h (July 2002) for vehicles used for work purposes

Vehicle type	Vehicle and freight time ($/h)
Passenger car	0.50
Light commercial vehicle	1.70
Medium commercial vehicle	6.10
Heavy commercial vehicle I	17.10
Heavy commercial vehicle II	28.10
Bus	17.10

Source: Economic Evaluation Manual (Volume 1) (NZTA 2010)

Table A2.4: Vehicle occupancy and travel purpose

Road category	Car				LCV				MCV and HCV			
	Occupancy	Travel purpose (%)			Occupancy	Travel purpose (%)			Occupancy	Travel purpose (%)		
		Work	Commute	Other		Work	Commute	Other		Work	Commute	Other
Rural strategic and rural other roads												
Weekday	1.6	40	10	50	1.6	75	5	20	1.3	90	5	5
Weekend	2.2	5	5	90	2.0	10	10	80	1.8	75	5	20
All periods	1.7	30	10	60	1.7	55	5	40	1.4	85	5	10

Source: Economic Evaluation Manual (Volume 1) (NZTA 2010)

3.4 EFFECT OF SPEED ON VEHICLE OPERATING COSTS

3.4.1 VOC related to cruise speed and gradient

Vehicle operating costs (VOC) per kilometre travelled as a function of speed and road gradient were calculated from formulae given in EEM Table A5.11 (NZTA 2010) for each vehicle type during 2009. Passenger car VOCs calculated by the formula are tabulated and graphed in EEM Table A5.1 shown below, but the actual formula for each vehicle type was used in the analysis for this study. The estimates did not need to be updated to 2009.

Table A5.11: Running cost by speed and gradient regression coefficients (cents/km – July 2008)

$$VOC_B = a + b \times GR + c \times \ln(S) + d \times GR^2 + e \times [\ln(S)]^2 + f \times GR \times \ln(S) + g \times GR^3 + h \times [\ln(S)]^3 + i \times GR \times [\ln(S)]^2 + j \times GR^2 \times \ln(S)$$

Regression coefficient	Vehicle class						Road category			
	PC	LCV	MCV	HCVI	HCVII	Bus	Urban arterial	Urban other	Rural strategic	Rural other
a	24.616	15.852	20.230	-75.602	-263.90	-125.50	15.837	19.898	5.1705	12.034
b ($\times 10^{-2}$)	-44.832	-109.65	-70.181	82.435	2722.4	-21.363	5.8087	-21.958	91.522	35.415
c	43.489	64.641	87.808	263.07	469.66	272.77	59.846	52.292	77.703	66.095
d ($\times 10^{-4}$)	-445.63	-118.58	2731.4	9566.1	15069	5637.9	193.04	-129.24	918.9	444.87
E	-21.157	-30.064	-39.668	-101.34	-159.79	-102.10	-26.979	-24.332	-33.024	-29.079
f ($\times 10^{-2}$)	38.558	68.678	55.741	-65.136	-1446.2	81.726	10.316	25.549	-36.259	-5.8716
g ($\times 10^{-4}$)	17.595	12.105	-165.84	-608.65	-1306.0	-413.78	-4.2281	-27.46	-83.300	-46.897
h	2.5663	3.6463	4.8935	11.615	17.174	11.711	3.2172	2.9233	3.8723	3.4431
i ($\times 10^{-3}$)	-61.237	-99.936	-147.07	-48.388	1796.9	-318.64	-30.26	-46.859	24.414	-11.163
j ($\times 10^{-3}$)	12.523	15.750	58.615	171.01	488.06	157.89	26.908	19.615	45.233	33.217

Notes: VOC_B = base vehicle operating costs in cents/km

GR = absolute value of average gradient (ie >0) over range of 0 – 12 percent

S = speed in km/h over range of 10 – 120km/h

ln = natural logarithm.

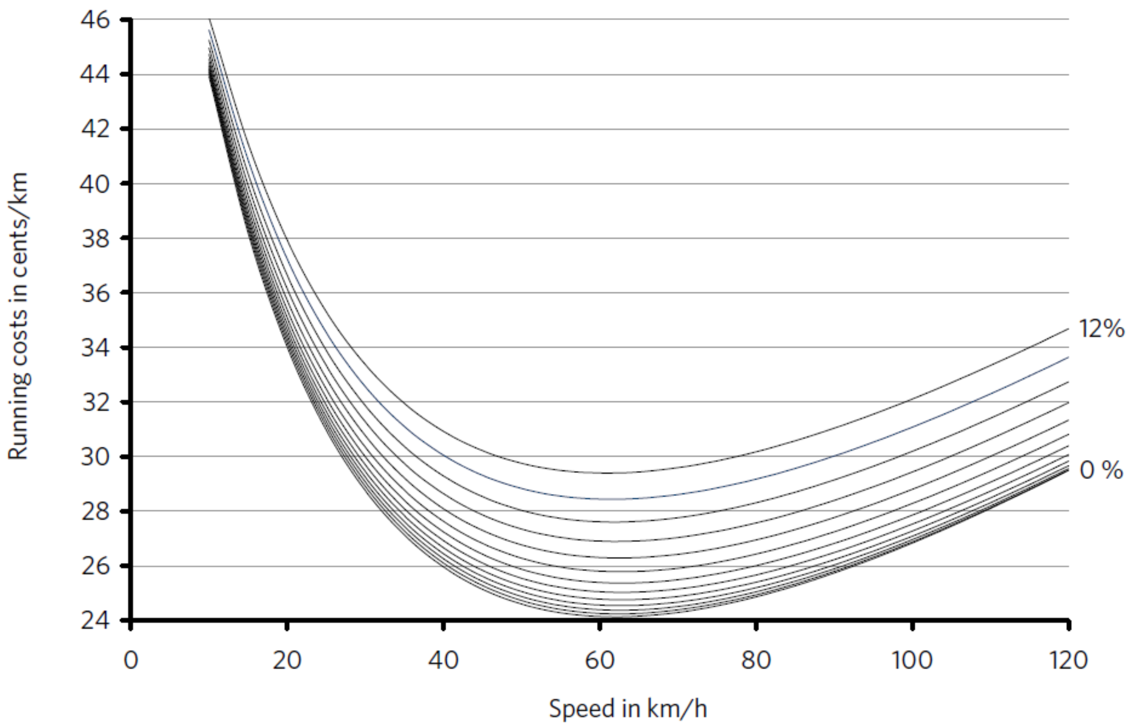
Sample equation for passenger cars (PC):

$$VOC_B = 24.616 - 44.832 \times 10^{-2} \times GR + 43.489 \times \ln(S) - 445.63 \times 10^{-4} \times GR^2 - 21.157 \times [\ln(S)]^2 + 38.558 \times 10^{-2} \times GR \times \ln(S) + 17.595 \times 10^{-4} \times GR^3 + 2.5663 \times [\ln(S)]^3 - 61.237 \times 10^{-3} \times GR \times [\ln(S)]^2 + 12.523 \times 10^{-3} \times GR^2 \times \ln(S)$$

Source: Economic Evaluation Manual (Volume 1) (NZTA 2010)

Table A5.1: Passenger car VOC by speed and gradient (cents/km – July 2008)

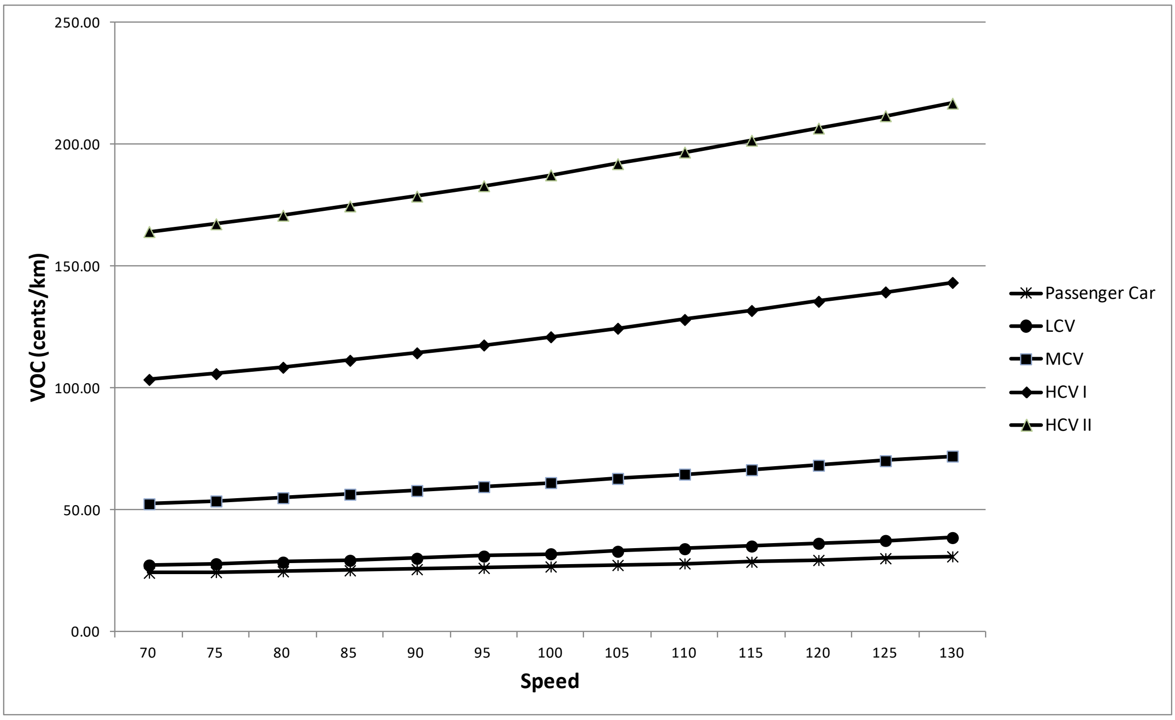
Speed (km/h)	Gradient in percent (both directions)												
	0	1	2	3	4	5	6	7	8	9	10	11	12
10	43.9	44.0	44.1	44.2	44.2	44.3	44.4	44.5	44.7	45.0	45.2	45.6	46.1
15	38.2	38.3	38.5	38.6	38.7	38.9	39.1	39.3	39.6	39.9	40.4	40.9	41.5
20	34.0	34.2	34.3	34.5	34.6	34.9	35.1	35.4	35.7	36.1	36.6	37.2	37.9
25	31.0	31.1	31.3	31.5	31.7	31.9	32.2	32.5	32.9	33.3	33.9	34.5	35.3
30	28.8	28.9	29.1	29.2	29.5	29.7	30.0	30.3	30.8	31.3	31.9	32.6	33.4
35	27.1	27.3	27.4	27.6	27.8	28.1	28.4	28.8	29.2	29.7	30.4	31.1	31.9
40	26.0	26.1	26.3	26.4	26.7	26.9	27.2	27.6	28.1	28.6	29.3	30.1	30.9
45	25.1	25.3	25.4	25.6	25.8	26.1	26.4	26.8	27.3	27.9	28.5	29.3	30.2
50	24.6	24.7	24.9	25.1	25.3	25.5	25.9	26.3	26.8	27.4	28.0	28.8	29.8
55	24.3	24.4	24.5	24.7	24.9	25.2	25.5	26.0	26.5	27.0	27.7	28.6	29.5
60	24.1	24.3	24.4	24.6	24.8	25.1	25.4	25.8	26.3	26.9	27.6	28.4	29.4
65	24.2	24.3	24.4	24.6	24.8	25.0	25.4	25.8	26.3	26.9	27.6	28.5	29.4
70	24.3	24.4	24.5	24.7	24.9	25.2	25.5	25.9	26.4	27.0	27.8	28.6	29.6
75	24.5	24.6	24.7	24.9	25.1	25.4	25.7	26.1	26.6	27.3	28.0	28.9	29.8
80	24.9	24.9	25.1	25.2	25.4	25.7	26.0	26.4	26.9	27.6	28.3	29.2	30.2
85	25.3	25.3	25.4	25.6	25.8	26.0	26.4	26.8	27.3	28.0	28.7	29.6	30.6
90	25.7	25.8	25.9	26.0	26.2	26.5	26.8	27.2	27.8	28.4	29.1	30.0	31.0
95	26.3	26.3	26.4	26.5	26.7	27.0	27.3	27.7	28.3	28.9	29.6	30.5	31.6
100	26.8	26.9	27.0	27.1	27.3	27.5	27.9	28.3	28.8	29.4	30.2	31.1	32.1
105	27.5	27.5	27.6	27.7	27.9	28.1	28.4	28.9	29.4	30.0	30.8	31.7	32.7
110	28.1	28.1	28.2	28.3	28.5	28.7	29.1	29.5	30.0	30.6	31.4	32.3	33.3
115	28.8	28.8	28.9	29.0	29.1	29.4	29.7	30.1	30.7	31.3	32.1	33.0	34.0
120	29.5	29.5	29.6	29.7	29.8	30.1	30.4	30.8	31.3	32.0	32.7	33.6	34.7



Source: Economic Evaluation Manual (Volume 1) (NZTA 2010)

Figure 1 shows the calculated VOC for each vehicle type as a function of speed in the range from 70 to 130 km/h, assuming a gradient of zero.

Figure 1: Vehicle operating costs per kilometre related to vehicle speed and type



In the analysis, the VOC for each vehicle type related to speed was calculated for each of three representative categories of gradient ranges found on New Zealand rural roads (Table 8). In each road category, the proportions of vehicle-kilometres travelled in mountainous (grade 7-11%), rolling (4-6%) and 'flat' terrain (1-3%) were used to weight the calculated costs to provide an average VOC per kilometre for the road category.

Table 8: Percentage of vehicle-km spent in each terrain by heavy and light vehicles

	Flat terrain		Rolling terrain		Mountainous	
Road Category	Heavy vehicles	Light vehicles	Heavy vehicles	Light vehicles	Heavy vehicles	Light vehicles
1. Motorways/ Expressways (divided)	51.73%	50.18%	45.49%	46.78%	2.78%	3.04%
2. High Volume National Strategic roads	40.97%	39.78%	51.25%	52.75%	7.78%	7.47%
3. Straight National & Regional Strategic roads	43.52%	43.68%	50.95%	51.03%	5.53%	5.30%
4. Winding National & Regional Strategic roads	3.80%	3.69%	74.35%	73.21%	21.85%	23.10%
5. Straight Regional Connectors & Distributors	39.84%	41.33%	53.62%	51.51%	6.54%	7.15%
6. Winding Regional Connectors & Distributors	3.61%	2.95%	70.55%	68.85%	25.80%	28.19%

3.4.2 Increase in VOC due to curves and stops

The additional VOC per curve and per stop due to reductions from cruise speed were calculated in an analogous way to additional travel time, using formulae based on VOC estimates in EEM Tables A5.7 (NZTA 2010). The formulae for the additional VOC per speed change cycle (deceleration and acceleration back to cruise speed) were also provided by MHW New Zealand Ltd on behalf of NZTA. MWH New Zealand indicated that the formulae were accurate to within 0.1 cents of the additional VOC per speed change cycle.

These additional costs were summed across all curves and stops in each road category, then added to the total VOC calculated as if vehicles had cruised throughout the full road length.

Table A5.25: Passenger car additional VOC due to speed change cycles (cents/speed cycle – July 2008)

Initial speed (km/h)	Additional VOC (in cents/speed cycle) by final speed																						
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
5	0.1																							
10	0.2	0.1																						
15	0.3	0.2	0.1																					
20	0.4	0.3	0.1	0.1																				
25	0.6	0.4	0.3	0.2	0.1																			
30	0.8	0.6	0.5	0.4	0.2	0.1																		
35	0.9	0.8	0.7	0.5	0.4	0.2	0.1																	
40	1.1	1.0	0.9	0.8	0.6	0.4	0.2	0.1																
45	1.4	1.2	1.1	1.0	0.8	0.6	0.4	0.2	0.1															
50	1.6	1.5	1.4	1.2	1.0	0.8	0.6	0.4	0.2	0.1														
55	1.8	1.7	1.6	1.5	1.3	1.0	0.8	0.6	0.4	0.2	0.1													
60	2.1	2.0	1.9	1.7	1.6	1.3	1.1	0.8	0.6	0.4	0.2	0.1												
65	2.4	2.3	2.2	2.0	1.8	1.6	1.3	1.1	0.9	0.6	0.4	0.2	0.1											
70	2.7	2.6	2.5	2.3	2.1	1.9	1.6	1.4	1.1	0.9	0.6	0.4	0.2	0.1										
75	3.0	2.9	2.8	2.6	2.4	2.2	1.9	1.7	1.4	1.2	0.9	0.7	0.4	0.2	0.1									
80	3.3	3.2	3.1	2.9	2.7	2.5	2.2	2.0	1.7	1.4	1.2	0.9	0.7	0.4	0.2	0.1								
85	3.6	3.5	3.4	3.3	3.1	2.8	2.5	2.3	2.0	1.7	1.5	1.2	0.9	0.7	0.4	0.2	0.1							
90	4.0	3.9	3.7	3.6	3.4	3.1	2.8	2.6	2.3	2.0	1.8	1.5	1.2	1.0	0.7	0.4	0.2	0.1						
95	4.3	4.2	4.1	3.9	3.7	3.4	3.1	2.9	2.6	2.3	2.0	1.8	1.5	1.2	1.0	0.7	0.4	0.2	0.1					
100	4.7	4.5	4.4	4.2	4.0	3.7	3.4	3.2	2.9	2.6	2.3	2.1	1.8	1.5	1.2	1.0	0.7	0.4	0.2	0.1				
105	5.0	4.9	4.7	4.6	4.3	4.0	3.8	3.5	3.2	2.9	2.6	2.3	2.1	1.8	1.5	1.2	1.0	0.7	0.4	0.2	0.1			
110	5.4	5.2	5.1	4.9	4.6	4.3	4.1	3.8	3.5	3.2	2.9	2.6	2.3	2.1	1.8	1.5	1.2	0.9	0.7	0.4	0.2	0.1		
115	5.7	5.6	5.4	5.2	5.0	4.7	4.4	4.1	3.8	3.5	3.2	2.9	2.6	2.3	2.0	1.8	1.5	1.2	0.9	0.7	0.4	0.2	0.1	
120	6.1	5.9	5.7	5.5	5.3	4.9	4.6	4.3	4.0	3.7	3.4	3.1	2.8	2.6	2.3	2.0	1.7	1.4	1.2	0.9	0.6	0.4	0.2	0.1

Source: Economic Evaluation Manual (Volume 1) (NZTA 2010)

3.5 EFFECT OF SPEED ON VEHICLE EMISSIONS

3.5.1 Carbon dioxide emissions and their unit cost

Carbon dioxide emissions are directly related to VOC in EEM Appendix A9.7 (NZTA 2010). VOC related to speed for each vehicle type was used to calculate annual carbon dioxide emissions (tonnes per year) and these were costed at NZ$40 per tonne.

3.5.2 Unit costs of other air pollution emissions in rural areas

Other air pollutants were considered to be predominantly an urban issue and their unit cost per tonne emitted in rural areas was discounted to 1% of the urban unit cost (Perovic et al 2008). The unit costs of air pollution emissions provided by Perovic et al (2008) in year 2007 A$ were:

- Carbon monoxide A$ 3 per tonne
- Hydrocarbons A$ 958 per tonne
- Oxides of nitrogen A$ 1,912 per tonne
- Particulates (PM10) A$ 304,298 per tonne

3.5.3 Emissions of carbon monoxide, nitrogen oxides and particulates

Emission rates of carbon monoxide, nitrogen oxides and particulates related to speed were calculated from formulae given in EEM Appendix A9.3 separately for light and heavy vehicle types (NZTA 2010).

Emission (g/vkt) = A x Speed^2 + B x Speed + C

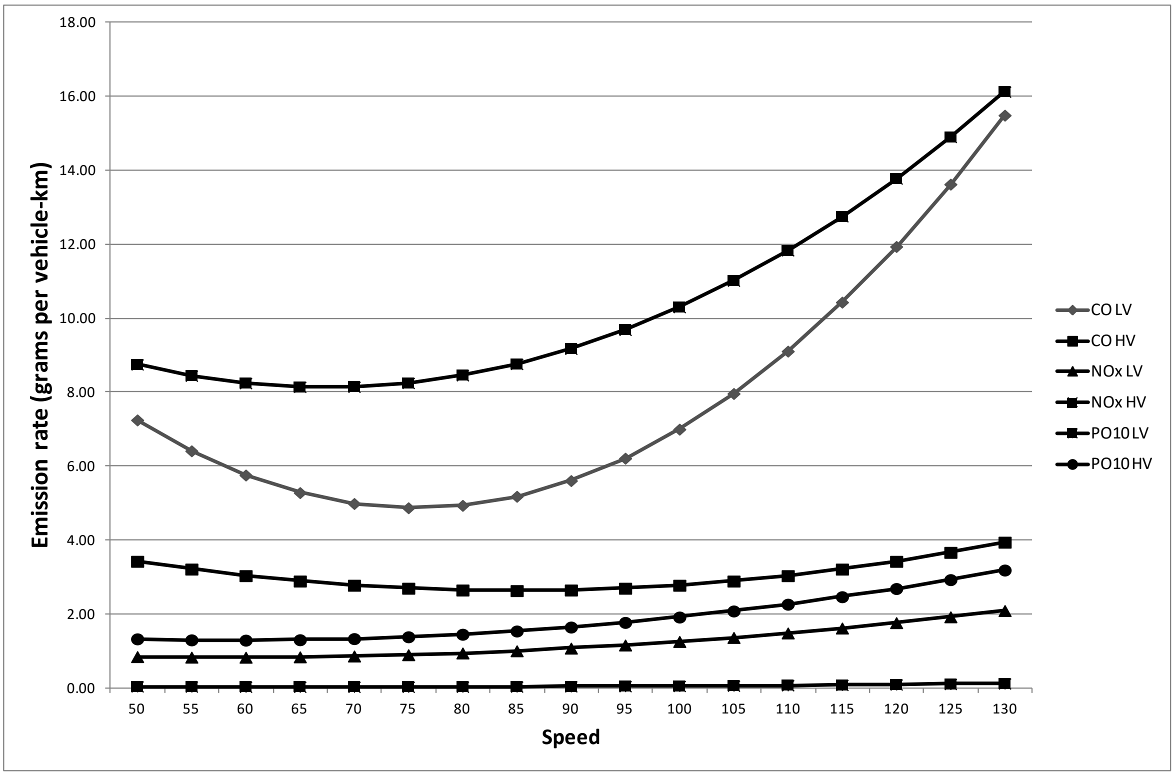
Where: Speed = average speed on link road from step 3

A, B, C = coefficients from table below

Emission	Vehicle	A	B	C
CO	Light	3.6×10^{-3}	-0.545	25.5
	Heavy	6.47×10^{-4}	-0.11	7.31
NO_x	Light	2.46×10^{-4}	-0.0287	1.67
	Heavy	2.04×10^{-3}	-0.275	17.4
PO_{10}	Light	2.45×10^{-5}	-0.00342	0.153
	Heavy	3.82×10^{-4}	-0.0455	2.65

Source: Economic Evaluation Manual (Volume 1) (NZTA 2010)

Figure 1a: Emission rates of carbon monoxide (CO), nitrogen oxides (NO_x) and particulates (PO_{10}) related to speed of light vehicles (LV) and heavy vehicles (HV)



3.5.4 Hydrocarbon emissions

Emission rates of hydrocarbons were derived from research conducted as part of the MASTER project (Robertson, Ward and Marsden 1998). They provided estimates of the levels of emissions from a typical stream of vehicles travelling at steady speeds at 80 and 90 km/h on flat roads. The traffic mix consisted of 15% trucks, of which 2/3 were heavy trucks, and 80% of the cars were fitted with catalytic converters. This traffic composition was considered to be reasonably representative of rural traffic in New Zealand.

Robertson et al's estimates have been extrapolated to estimate the air pollution emission impacts (in grams per km) for hydrocarbons. Information presented by Ward et al (1998) suggested that it was reasonable to extrapolate its emission rate as a linear function of speed in the range from 70 to 130 km/h.

3.5.5 Increase in emissions due to curves and stops

Traffic slowing for sharp bends would need to decelerate then accelerate to normal cruising speeds, resulting in increased emissions of air pollutants. The impact of variations in traffic speed on fuel consumption and emissions, due to acceleration and deceleration, has been modelled by the Virginia Polytechnic Institute and State University in the USA (Ding 2000). Ding (2000) developed statistically-based mathematical models linking the rate of fuel consumption and pollutant emitted (HC, CO and NO_x) per kilometre to the average speed, the average speed squared, the variance of speeds, the number of stops, and parameters reflecting the variation in acceleration rates and kinetic energy. The models had an accuracy of 88%-96% when compared with instantaneous microscopic models (Ahn et al 1999). These models were used to estimate the increases in emission rates for vehicles travelling at a given cruise speed encountering 50 sharp bends and stopping three times, to illustrate the influence of curves and stops, compared with the straight, featureless road section (Table 9). Further details of the models are given by Cameron (2003).

Table 9: Relative rates of air pollutant emissions due to slowing from given cruise speeds for 50 sharp curves (down to 70 km/h negotiation speed) and 3 stops per 100 kilometres

		Relative rates on curvy road with stops, compared to straight road without stops			
Cruise speed (km/h)	Average speed over 100 km section (km/h)	PO_{10}	HC	CO	NO_x
70	69.78	1.029	1.068	1.078	1.082
75	74.60	1.056	1.114	1.131	1.139
80	79.43	1.083	1.159	1.185	1.195
85	84.04	1.104	1.191	1.224	1.237
90	88.49	1.166	1.294	1.351	1.374
95	92.76	1.244	1.422	1.516	1.553
100	96.82	1.350	1.599	1.750	1.810

This method was used to estimate the increased emission rates associated with deceleration from cruise speeds for stops and sharp curves (those less than 200 m radius) in each rural road category, and then acceleration again, for cruise speeds between 70 and 100 km/h. The density of stops and sharp curves per 100 kilometre of each category of road in New Zealand can be seen in Table 6. The categories described as winding roads have 115 (Category 4) and 243 (Category 6) sharp curves per 100 kilometres. The density of sharp curves on New Zealand winding roads is substantially higher than that used for the analysis of curvy roads in Australia by Cameron (2003, 2004, 2011, 2012).

For cruise speeds in excess of 100 km/h, Ding's (2000) method estimated relative rates of emissions due to stops and curves that were substantially higher than the relative rates for VOC (and hence carbon dioxide emissions) calculated for each road category as described in Section 3.4.2 based on procedures from EEM (NZTA 2010). For this reason it was decided to cap the relative rates for emissions other than carbon dioxide at the rates calculated for slowing from 100 km/h cruise speed in each road category. This may result in under-estimation of the emission rates due to slowing for stops and curves from high cruise speeds. However the higher emission rates for pollutants other than carbon dioxide would have been valued at only 1% of their urban unit cost and hence the error is small.

To recap, carbon dioxide emissions were linked to VOC at each cruise speed and their increase related to curves and stops was estimated indirectly through the increase in VOC in these road environments (Sections 3.4.2 and 3.5.1). The costs associated with carbon dioxide emissions were at least 93% of the estimated total cost of air pollution emissions, in part because of the discounting of the unit cost of the other pollutants in rural areas.

Noise pollution related to speed could not be estimated nor valued. This social cost was considered to be small along rural highways in New Zealand.

3.6 RURAL ROAD USE

The analysis of the effects of different cruise speeds, compared with current mean free speeds in each road category, made use of actual traffic volumes in each category. This allowed the total annual costs of road trauma, travel time, vehicle operations, and air pollution emissions to be estimated, compared across road categories, and summed to estimate the total economic impact of different speeds by each vehicle type to be seen.

Estimated annual average daily traffic volumes of each vehicle type in each rural road category during 2006-2010 were provided by NZTA (Table 10).

Table 10: Annual Average Daily Traffic (AADT) on rural roads during 2006-2010

Road Category	Passenger cars	Light commercial vehicles (LCV)	Medium commercial vehicle (MCV)	Heavy commercial vehicle I (HCV I)	Heavy commercial vehicle II (HCV II)
1. Motorways/ Expressways (divided)	22,156	2,841	538	538	538
2. High Volume National Strategic roads	10,169	1,304	448	448	448
3. Straight National & Regional Strategic roads	3,691	473	200	200	200
4. Winding National & Regional Strategic roads	3,446	442	197	197	197
5. Straight Regional Connectors & Distributors	1,459	162	83	83	62

6. Winding Regional Connectors & Distributors	1,480	164	82	82	62

3.6 ESTIMATION OF OPTIMUM SPEEDS

The total costs of road trauma, travel time, vehicle operations and air pollution emissions were calculated for each cruise speed in the range 70 to 130 km/h for each vehicle type and then aggregated into light vehicles (cars and LCVs) and heavy vehicles (MCVs and HCVs I and II). Within each road category, the cruise speed that minimises the total cost for light vehicles was found and a similar optimum cruise speed was found for heavy vehicles (no less than 70 km/h). The total cost if each vehicle type travelled at its optimum speed in each road category was then aggregated across all rural State Highways and compared with the total cost where vehicles travel at their current cruise speeds, given in Table 2.

3.7 ASSUMPTIONS FOR THE ANALYSIS

1. Crashes involving material damage only, and no personal injury, were not included in the analysis of crash changes with speed, and the change in these crashes with changes in mean speeds (albeit to a lesser extent than fatal and injury crashes) was not valued.
2. The travel time savings (costs) associated with increased (decreased) speeds on the rural highways are of sufficient magnitude to be aggregated and valued.
3. The economic valuations of travel time, road trauma, and air pollution emissions provided an appropriate basis for an analysis which summates their values, together with vehicle operating costs, in a way which represents the total social costs of each speed. In other words, the valuations are an appropriate basis for aggregating these tangible and intangible values of each impact to provide the total cost to society.

5. OPTIMUM SPEEDS IN EACH ROAD CATEGORY

5.1 RURAL MOTORWAYS/EXPRESSWAYS (CATEGORY 1)

The results of the analysis for rural motorways/expressways in New Zealand are given in Appendix B and are summarised in Table 11 for each cruise speed. The cruise speed in the range from 70 to 130 km/h that minimises the total economic cost of speed (to the nearest 5 km/h step) is shown in bold separately for heavy vehicles and for cars and light commercial vehicles (LCVs). Table 11 also shows the aggregated total economic cost of each cruise speed if performed by both the heavy and light vehicles. The single cruise speed that minimises the total economic cost across all types of vehicle is 100 km/h.

Table 11: Economic impact of different cruise speeds on motorways/expressways

$'000/year	70 km/h	75 km/h	80 km/h	85 km/h	90 km/h	95 km/h	100 km/h
Vehicle op. costs	1,337,579	1,355,497	1,377,788	1,403,891	1,434,710	1,468,903	1,506,467
Time costs	1,584,812	1,479,834	1,388,020	1,307,146	1,235,597	1,172,518	1,116,894
Crash costs	36,001	41,745	48,199	55,434	63,525	72,549	82,589
Air pollution costs	61,179	62,098	63,239	64,587	66,221	68,055	70,097

Total	3,019,570	2,939,175	2,877,246	2,831,058	2,800,053	2,782,025	**2,776,047**

of which:

Heavy vehicles	603,001	599,062	**597,573**	598,214	602,277	608,105	615,398
Cars & LCVs	2,416,569	2,340,113	2,279,673	2,232,844	2,197,776	2,173,920	2,160,649

Table 11 (cont.): Economic impact of different cruise speeds on motorways/expressways

$'000/year	105 km/h	110 km/h	115 km/h	120 km/h	125 km/h	130 km/h
Vehicle op. costs	1,546,192	1,587,810	1,631,088	1,675,822	1,721,837	1,768,978
Time costs	1,066,918	1,021,814	980,937	943,748	909,791	878,678
Crash costs	93,733	106,070	119,696	134,710	151,216	169,320
Air pollution costs	72,190	74,407	76,739	79,177	81,715	84,346
Total	2,779,034	2,790,102	2,808,460	2,833,458	2,864,559	2,901,322

of which:

Heavy vehicles	623,946	633,692	644,548	656,441	669,313	683,118
Cars & LCVs	**2,155,088**	2,156,410	2,163,912	2,177,017	2,195,246	2,218,204

The speed that minimises the economic cost on motorways/expressways is substantially different for cars and LCVs (105 km/h) compared with the optimum speed for trucks (80 km/h). The optimum speed for cars and LCVs is shown with an arrow in Figure 2 and similarly for trucks in Figure 3.

Figure 2: Impacts of car and LCV speeds on rural motorways/expressways **($'000 per year)**

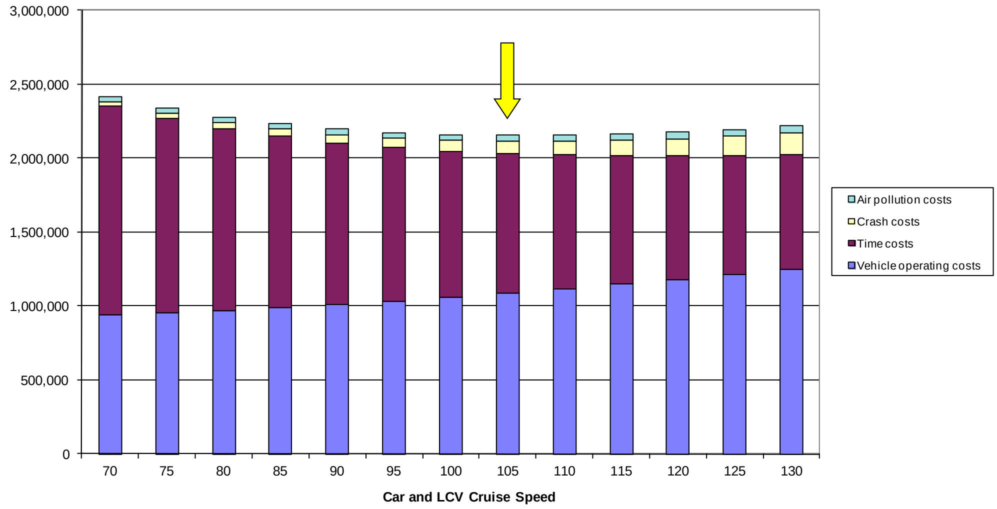
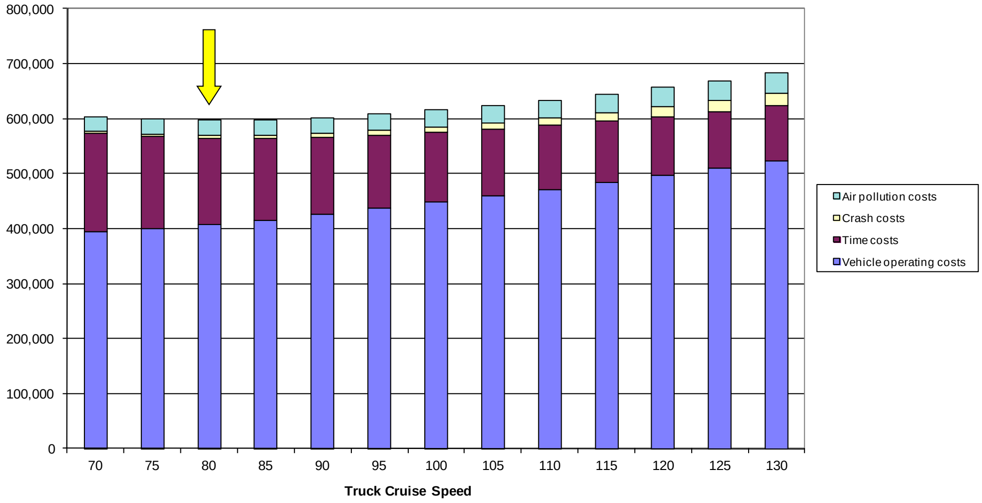


Figure 3: Impacts of truck speeds on rural motorways/expressways ($'000 per year)



If the light vehicles increased their cruise speed to 105 km/h and trucks reduced their speed on rural motorways to 80 km/h, there would be about one additional fatal crash per year, eight additional serious injury crashes and 50 additional minor injury crashes. The total economic impact would be a saving of $13.9 million per year (0.5%) because total travel time costs would be reduced by 2.9% although crash costs would be increased by 11.1% and vehicle operating costs increased by 0.8% (Table 12).

The situation on rural motorways contrasts with all other rural road categories analysed in this study. In each of the other categories of State Highway, the optimum speed for both light vehicles and trucks was found to be less than the current cruise speed for each vehicle type (see Sections 5.2-5.4). Hence there would be savings in road trauma as well as reductions in total economic costs in each road category (except motorways) if vehicles changed their speeds to the optimum speeds.

Table 12: Economic impact if all vehicles changed to travelling at their optimum speed on rural motorways/expressways (Category 1 roads)

$'000/year	**Before**	**After**	**Change**	
Vehicle operating costs	1,483,293	1,494,464	11170	0.8 %
Time costs	1,136,251	1,102,732	-33519	-2.9 %
Crash costs	78,685	87,429	8,744	11.1%
Air pollution costs	68,336	68,036	-301	-0.4 %
Total	**2,766,566**	**2,752,661**		
Change			**-13,905**	**-0.5 %**

5.2 HIGH VOLUME NATIONAL STRATEGIC ROADS (CATEGORY 2)

The results of the analysis for high volume rural National Strategic roads are given in Appendix C. The speeds that minimise the economic cost on these roads are 85 km/h for cars and LCVs (Figure 4) and 70 km/h for trucks (Figure 5).

If these two vehicle types reduced their current cruise speeds on high volume National Strategic roads to their optimum speeds, it is estimated that the total economic impact would be a saving of $25.3 million per year (1.8%) (Table 13).

When comparing Figures 4 and 5 with Figures 2 and 3 for motorways/expressways, it can be seen that the crash costs contribute a substantially greater proportion of the total social costs of each speed. This is because the casualty crash rate per 100 million vehicle-kilometres on the high volume National Strategic roads is more than twice the rate on motorways/expressways (Table 3) and the crashes have more severe injury outcomes.

Figure 4: Impacts of car and LCV speeds on High Volume National Strategic roads ($'000 p.a.)

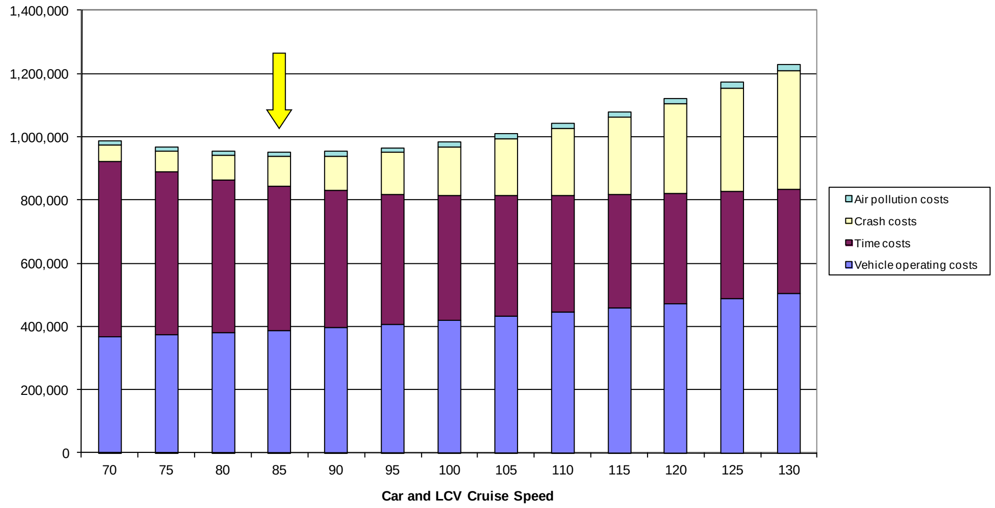


Figure 5: Impacts of truck speeds on High Volume National Strategic roads ($'000 p.a.)

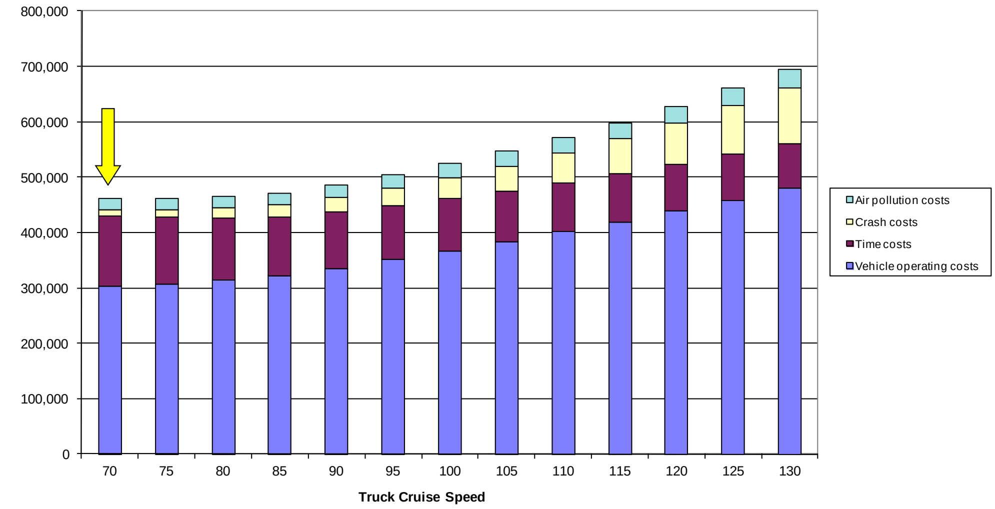


Table 13: Economic impact if all vehicles changed to travelling at their optimum speed on high volume rural National Strategic roads (Category 2 roads)

$'000/year	**Before**	**After**	**Change**	
Vehicle operating costs	730,208	688,927	-41281	-5.7 %
Time costs	521,547	585,799	64252	12.3 %
Crash costs	149,140	103,389	-45,752	-30.7%
Air pollution costs	37,015	34,540	-2,475	-6.7 %
Total	**1,437,910**	**1,412,655**		
Change			**-25,256**	**-1.8 %**

5.3 NATIONAL & REGIONAL STRATEGIC ROADS (CATEGORIES 3 & 4)

Other National Strategic roads and the Regional Strategic roads carry lower traffic volumes than the Category 2 roads. Separate analysis was conducted for the relatively straight National and Regional Strategic roads (Category 3) and those that have more winding alignments (Category 4). The density of curves in each radius category for each of these two sub-classes of rural road are given in Table 6. The two sub-classes also differ substantially in terms of the proportion of vehicle travel conducted in rolling and mountainous terrain (Table 8). The detailed results of the analysis for the Category 3 and 4 roads are given in Appendices D and E, respectively.

Figures 6 and 7 show that the speed of cars and LCVs that minimises the economic cost on these roads is 80 km/h on both the straight and winding National and Regional Strategic roads. For trucks, a speed of 70 km/h minimises the economic cost on both the straight and winding roads of this type (Figures 8 and 9), within the range of speeds down to 70 km/h considered in this analysis. (Speeds below 70 km/h in this road environment will be examined in the sensitivity analysis in Section 7.)

Figure 6: Impacts of car & LCV speeds on <u>straight</u> National & Regional Strategic roads ($'000 pa)

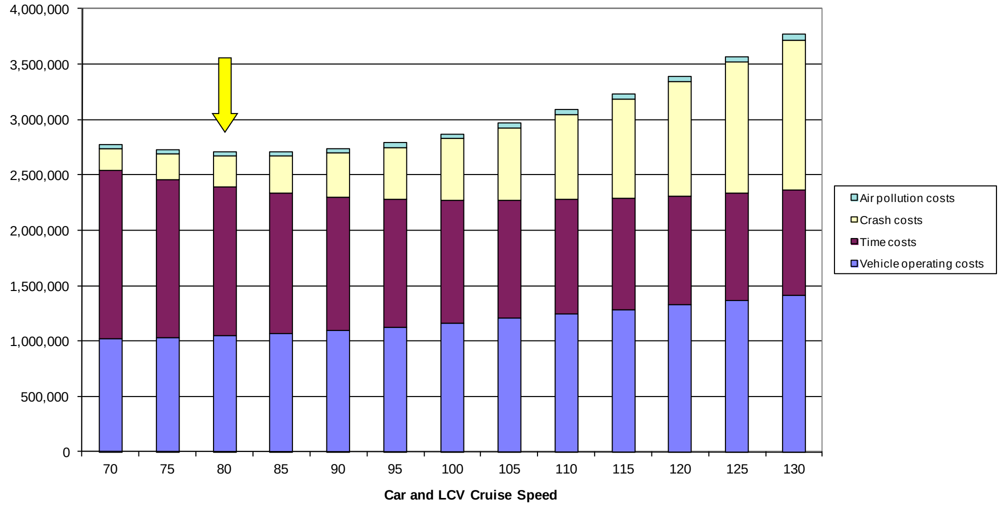


Figure 7: Impacts of car & LCV speeds on <u>winding</u> National & Regional Strategic roads ($'000 pa)

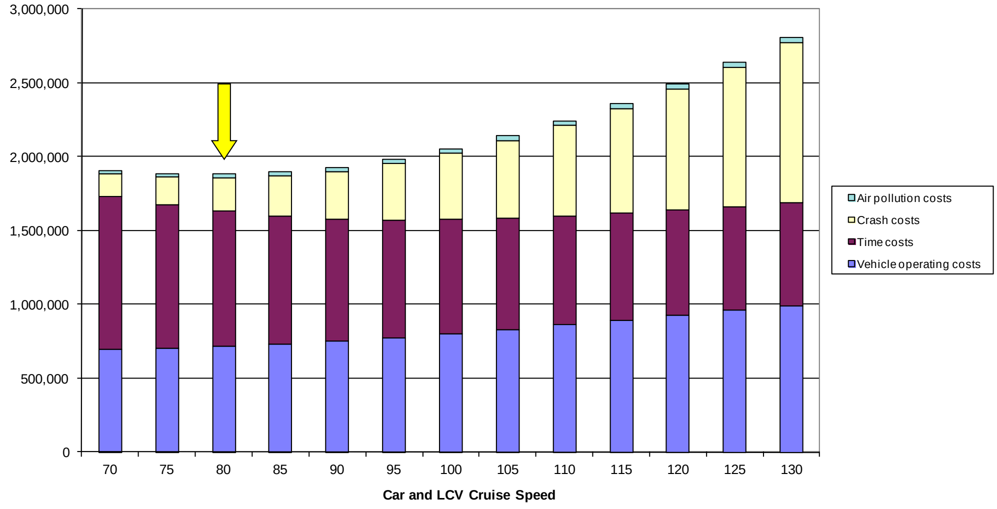


Figure 8: Impacts of truck speeds on straight National & Regional Strategic roads ($'000 p.a,)

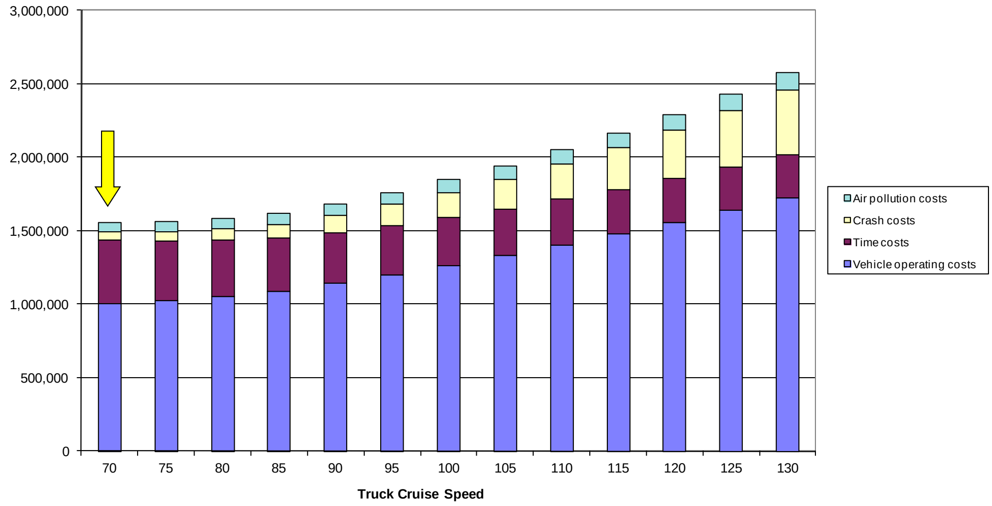
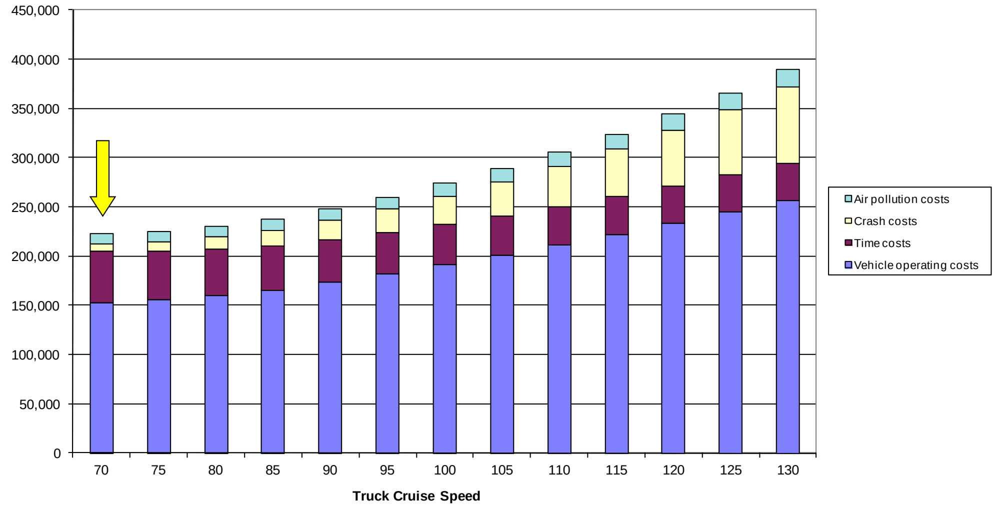


Figure 9: Impacts of truck speeds on winding National & Regional Strategic roads ($'000 p.a.)



5.4 REGIONAL CONNECTOR & DISTRIBUTOR ROADS (CATEGORIES 5 & 6)

For the Regional Connector and Distributor roads, separate analysis was also conducted for the relatively straight (Category 5) and winding roads (Category 6). The density of curves on each of these two sub-classes of rural road is given in Table 6. While the curve density on Category 5 roads is less than on Category 6, it is not much less than the curve density on Category 4 roads labelled "winding" National and Regional Strategic roads.

However, the Category 5 and 6 roads do differ substantially in terms of the proportion of vehicle travel conducted in rolling and mountainous terrain (Table 8). Category 5 roads also have substantially lower proportions of travel in rolling and mountainous terrain than Category 4 roads.

The detailed results of the analysis for the Category 5 and 6 roads are given in Appendices F and G, respectively. Figures 10 and 11 show that the speeds of cars and LCVs that minimises the economic cost on the straight roads is 80 km/h, but only 70 km/h on winding Regional Connector and Distributor roads. For trucks, a speed of 70 km/h minimises the economic cost on both the straight and winding roads of this type (Figures 12 and 13), within the range of speeds down to 70 km/h considered in this analysis.

Figure 10: Impacts of car & LCV speeds on straight Regional Connector & Distributor roads

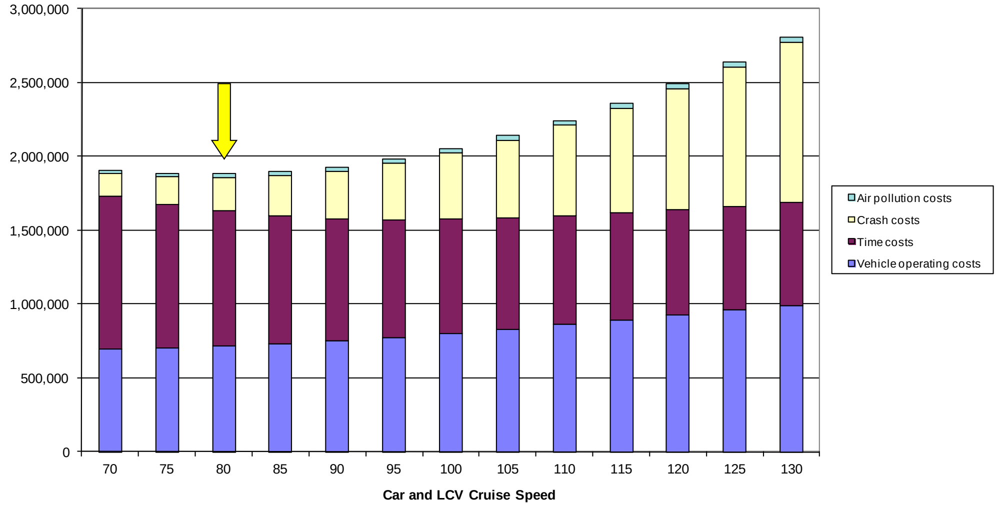


Figure 11: Impacts of car & LCV speeds on winding Regional Connector & Distributor roads ($'000 p.a.)

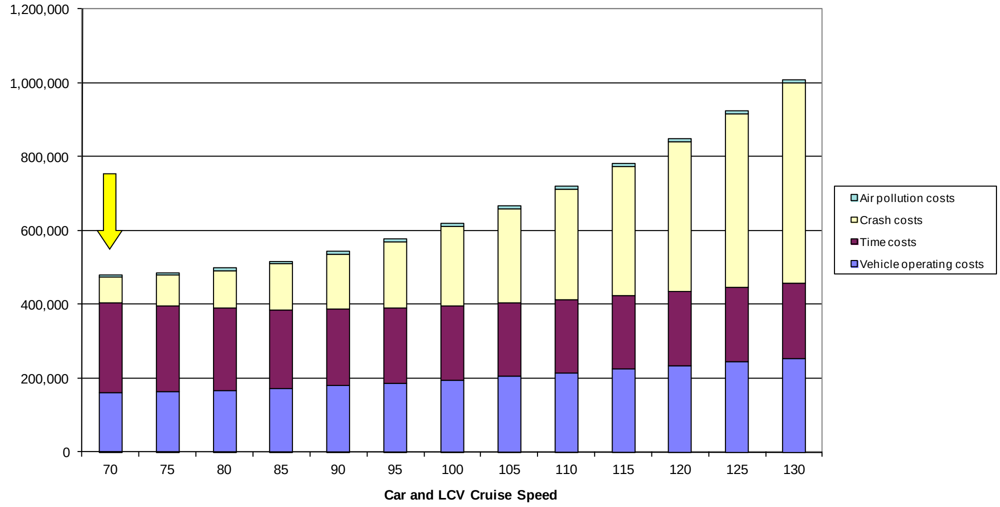


Figure 12: Impacts of truck speeds on straight Regional Connector & Distributor roads ($'000 pa)

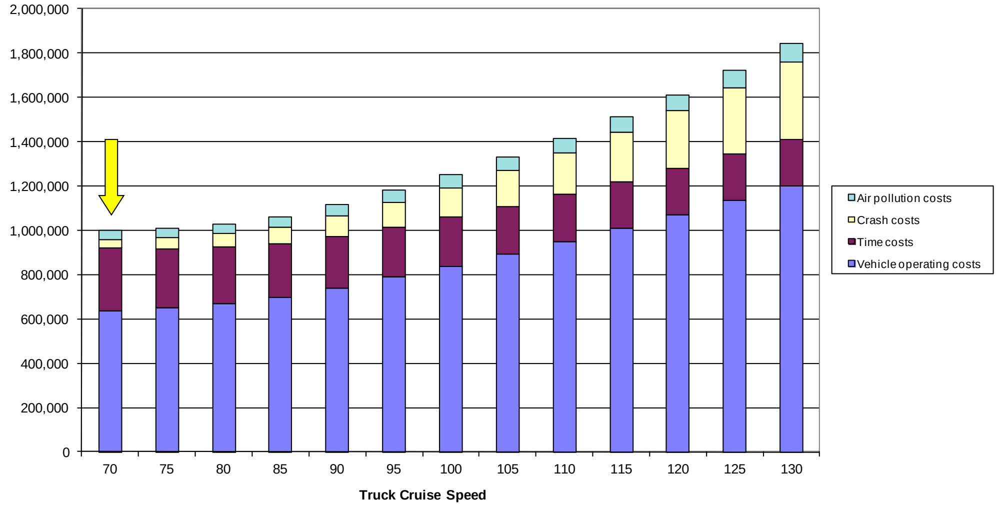
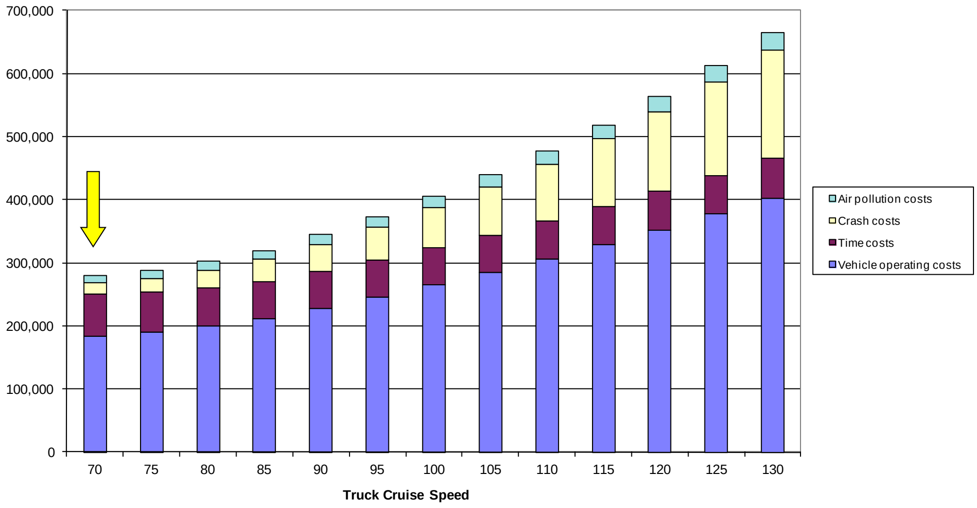


Figure 13: Impacts of truck speeds on winding Regional Connector & Distributor roads ($'000 p.a.)



6. IMPACT IF ALL VEHICLES TRAVELLED AT THEIR OPTIMUM SPEED

If cruise speeds in each category of rural highway were to be moved closer to the optimum speeds, there could be a substantial net gain in total economic costs across the road network. This is because a large proportion of rural road travel (and an even larger proportion of rural crashes) is on undivided roads where the optimum speeds are below current cruise speeds.

Table 14 summarises the estimate (to the nearest 5 km/h) of the optimum speed in each road category for the light vehicles and trucks separately. The optimum speeds are compared with the current cruise speeds (from Table 2).

Table 14: Current cruise speeds by vehicle type and estimated optimum speeds (not less than 70 km/h).

	Current cruise speeds on straight sections of rural highways (km/h)				Optimum cruise speeds (km/h)	
Road Category	Cars & light commercial vehicles (LCV)	Medium commercial vehicles (MCV)	Heavy commercial vehicles I (HCV I)	Heavy commercial vehicles II (HCV II)	Light vehicles (Cars & LCVs)	Heavy vehicles (MCVs & HCVs)
1. Motorways/Expressways (divided four-lane) roads	99.1	90.7	92.5	91.5	105	80
2. High Volume National Strategic roads	93.9	86.1	87.7	86.9	85	70
3. Straight National & Regional Strategic roads	95.8	87.8	89.5	88.6	80	70
4. Winding National & Regional Strategic roads	83.6	77.2	78.4	77.8	75	70
5. Straight Regional Connectors & Distributors	95.7	87.7	89.4	88.5	80	70
6. Winding Regional Connectors & Distributors	79.7	73.9	74.9	74.4	70	70

Compared with the existing situation, assuming all vehicles travel at current cruise speeds, the change to travelling at the optimum speed in each road environment would result in an overall 11% increase in travel time, 17% reduction in casualty crashes, and 7% to 18% reduction in air pollution emissions of various types (Table 15).

Table 15: Physical impact if all vehicles changed to travelling at their optimum speed, compared to travelling at their current speeds.

Type of impact		**Before**	**After**	**Change**	
Total travel time on link, hours/day		466,877	515,889	49,012	10.5 %
Number of Casualty Crashes per year		8,728	7,240	-1,489	-17.1%
Emissions, t/year	Carbon monoxide CO	115,307	98,560	-16,747	-14.5 %
	Hydrocarbons HC	7,129	6,168	-961	-13.5 %
	Oxides of nitrogen NO_x	37,095	31,169	-5,926	-16.0 %
	Particles PM	3,542	2,908	-633	-17.9 %
	Carbon dioxide CO_2	8,027,707	7,462,776	-564,931	-7.0 %

The reduction in casualty crashes is estimated to represent an annual saving of 90 fatal crashes (approximately 60% of the fatal crashes on rural State Highways), 334 serious injury crashes, and 1,065 minor injury crashes (Table 16). When these savings in road trauma are valued using the unit costs in Section 3.2.4, there would be 39% reduction in crash costs on rural highways (Table 17). The overall economic impact if all vehicles travelled at their optimum speeds was estimated to be a saving of $482 million per annum in total social costs or 3.7% reduction in the estimated $13.1 billion annual cost of rural State Highway travel in New Zealand.

Table 16: Estimated crash reductions on rural State Highways per year (negative figures are estimated crash increases).

	Estimated crash savings due to changes to optimum speeds				
Road category	Fatal crashes p.a.	Serious injury crashes p.a.	Other injury crashes p.a.	Annual casualty crashes (estimate)	Casualty crash saving (% p.a.)
1. Motorways/Expressways (divided four-lane) roads	-0.9	-7.7	-50.1	999.0	-5.9%
2. High Volume National Strategic roads	7.3	26.0	80.9	827.7	13.8%
3. Straight National & Regional Strategic roads	41.8	158.1	519.0	3280.6	21.9%
4. Winding National & Regional Strategic roads	2.8	10.1	31.5	329.6	13.5%
5. Straight Regional Connector & Distributor roads	33.0	125.1	411.1	2583.0	22.0%
6. Winding Regional Connector & Distributor roads	5.9	22.5	72.4	671.5	15.0%
TOTAL CRASH SAVINGS p.a.	**89.8**	**334.1**	**1064.8**	8691.4	**17.1%**
Annual crashes by severity (est.)	148.4	1006.6	7536.4		

PERCENT CRASH SAVINGS	60.5%	33.2%	14.1%

Table 17: Economic impact if all vehicles changed to travelling at their optimum speed.

$'000/year	**Before**	**After**	**Change**	
Vehicle operating costs	6,617,280	6,202,356	-414,924	-6.3 %
Time costs	4,661,854	5,192,801	530,947	11.4 %
Crash costs	1,484,548	911,946	-572,602	-38.6%
Air pollution costs	335,556	310,396	-25,160	-7.5 %
Total	**13,099,238**	**12,617,499**		
Change			**-481,739**	**-3.7 %**

7. SENSITIVITY ANALYSIS

The analysis described in this report included many assumptions, constraints and cost valuations. Three of these were examined in this section to test the sensitivity of the estimates of optimum speed to the following variations on the economic analysis:

1. Cruise speeds below 70 km/h for each vehicle type (where warranted)
2. Increased valuation of travel time costs
3. Ignoring under-reporting of non-fatal reported crashes.

The results of the sensitivity analysis are shown in Table 17 and are discussed in the following sections.

Table 17: Estimated optimum speeds resulting from variations in the economic analysis

	Optimum cruise speeds without 70 km/h lower limit		Optimum cruise speeds with travel time costs per hour doubled		Optimum cruise speeds based on reported crashes (ignoring under-reporting)	
Road Category	Light vehicles (Cars & LCVs)	Heavy vehicles (MCVs & HCVs)	Light vehicles (Cars & LCVs)	Heavy vehicles (MCVs & HCVs)	Light vehicles (Cars & LCVs)	Heavy vehicles (MCVs & HCVs)
1. Motorways/ Expressways (divided)	105	80	130	95	110	80
2. High Volume National Strategic roads	85	70	95	85	90	75
3. Straight National & Regional Strategic roads	80	70	95	80	85	70
4. Winding National & Regional Strategic roads	75	65	85	75	80	65
5. Straight Regional Connectors & Distributors	80	70	90	75	80	70

6. Winding Regional Connectors & Distributors	65	55	75	65	70	55

7.1 CRUISE SPEEDS BELOW 70 KM/H

The economic analysis of cruise speeds for each vehicle type examined only speeds in the range from 70 to 130 km/h in steps of 5 km/h. The optimum speeds recorded in Figures 2 to 13 and Table 14 were those for which the total economic cost was minimised in that speed range. Selected analysis was conducted to examine whether there was a lower total cost at speeds below 70 km/h for those vehicle types (principally heavy vehicles) and road categories for which the optimum speed was recorded as 70 km/h in Table 14.

The analysis was modified to cover speeds from 50 to 110 km/h. For the speeds below 70 km/h, adjustment factors to reflect the additional air pollution emissions (except carbon dioxide) due to slowing for stops and accelerating again were not available from previous analysis based on Ding's (2000) models. As described in Section 3.5.5, Ding's models had been used to estimate factors for slowing for stops and for sharp curves with negotiation speeds of 70 km/h; such curves were not relevant for cruise speeds of 70 km/h or less. Table 9 illustrates that the adjustment factor for stops alone associated with cruise speeds of 70 km/h or less is between 1 and 1.1. For the sensitivity analysis, no adjustment was made to the air pollution emissions associated with slowing from cruise speeds in the range 50 to 65 km/h. The exception to this was in the case of carbon dioxide emissions, which were estimated as a function of VOC and which in turn was adjusted for the number of stops and slowings for curves of different radii, from cruise speeds in the range 50 to 65 km/h, as described in Section 3.4.2.

Only in the case of heavy vehicles on Category 4 roads (Figure 14) and on Category 6 roads for both light (Figure 15) and heavy vehicles (Figure 16) did the extended analysis reveal that the total economic cost was below 70 km/h for those cases recorded as 70 km/h in Table 14. In the remaining cases, the sensitivity analysis confirmed that 70 km/h was the optimum speed.

In practice, the lower optimum speeds revealed in the extended analysis made very little difference to the total economic cost compared with 70 km/h. However, as can be seen in Figures 14 to 16, the crash costs associated with these lower optimum speeds are clearly smaller than the crash costs at a cruise speed of 70 km/h. If speed limits lower than 70 km/h could be considered on these winding rural roads in New Zealand, then this may result in further crash reductions than those estimated in Table 16 for Category 4 and 6 roads.

Figure 14: Impacts of truck speeds on winding National & Regional Strategic roads ($'000 p.a.)

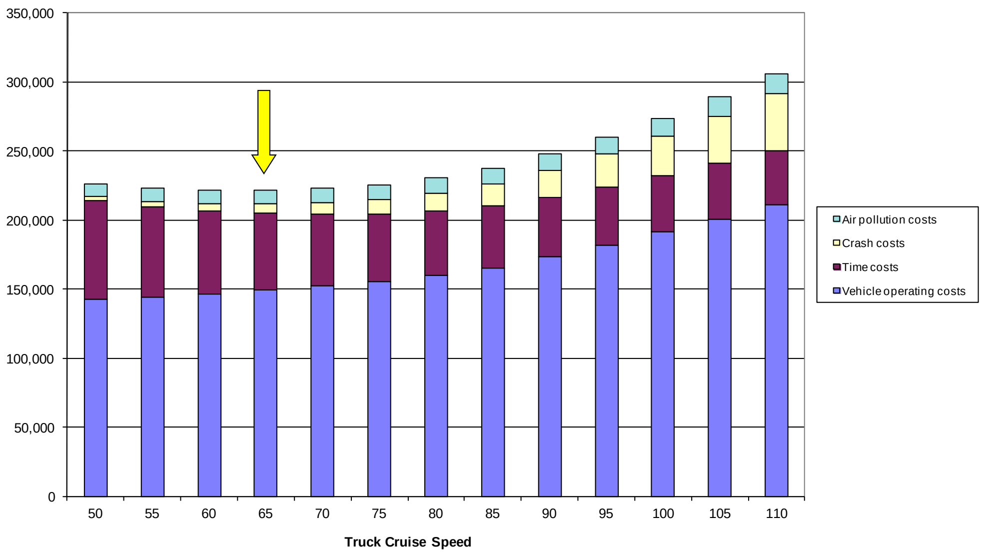


Figure 15: Impacts of car & LCV speeds on winding Regional Connector & Distributor roads ($'000 p.a.)

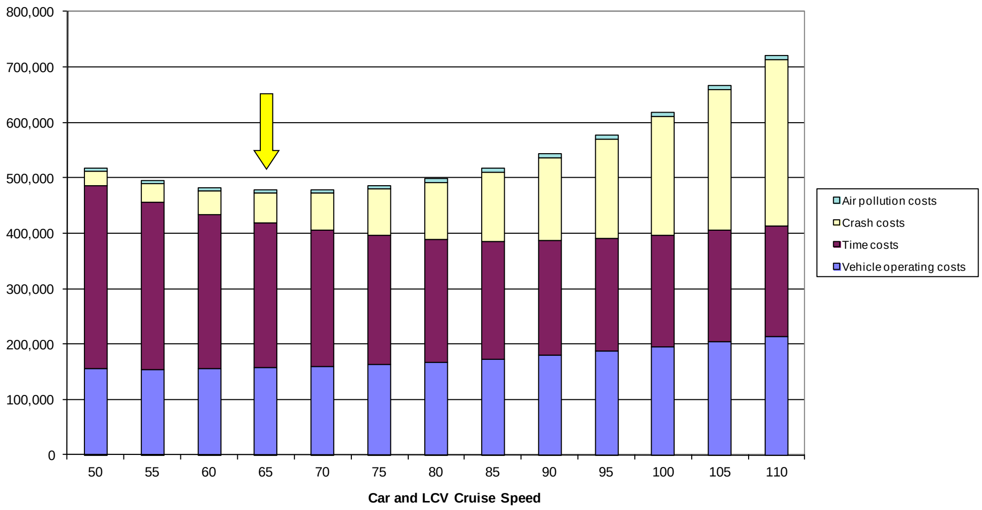
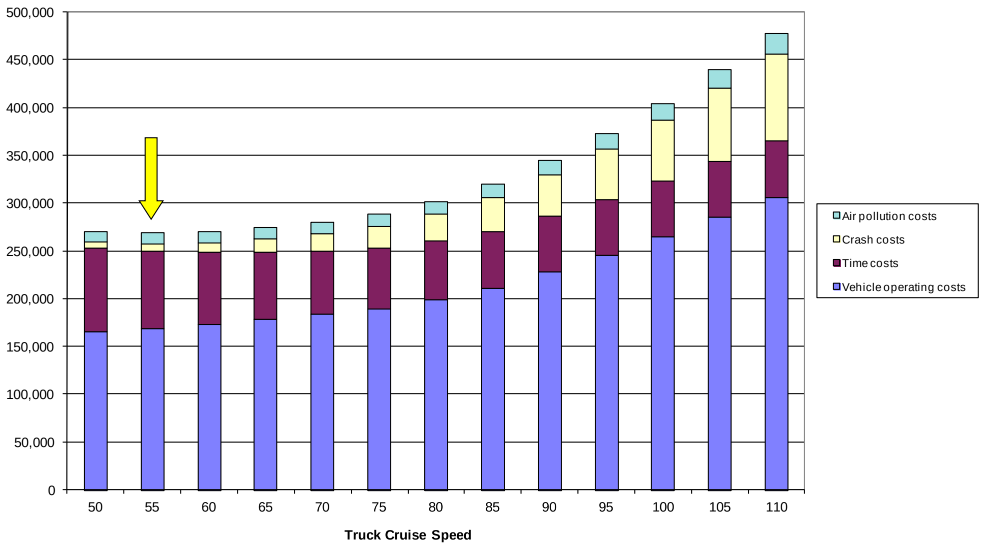


Figure 16: Impacts of truck speeds on winding Regional Connector & Distributor roads ($'000 p.a.)



7.2 INCREASED VALUATION OF TRAVEL TIME COSTS

It has been suggested that NZTA's (2010) Economic Evaluation Manual undervalues the unit costs of travel time. To test the sensitivity to the unit values per hour given in Tables A4.1 and A4.2 of EEM, these values were doubled and the optimum speeds re-estimated in the same way as described in Sections 5.1 to 5.4.

The re-estimated optimum speeds shown in Table 17 are generally 10 to 15 km/h higher than those estimated using the unit travel time values in EEM, with the optimum for cars and LCVs on motorways/expressways being estimated as 130 km/h compared with 105 km/h. Thus it can be seen the optimum speeds are sensitive to the values placed on travel time in a similar way as their sensitivity to valuation of road crash costs (Cameron 2012).

7.3 IGNORING UNDER-REPORTING OF NON-FATAL REPORTED CRASHES

EEM Table A6.20(a) requires that non-fatal reported crashes on motorways (both serious and minor injury crashes) be increased by 90% to estimate actual numbers, and that on other 80 or 100 km/h speed limit roads the serious and minor injury crashes be increased by factors of 1.9 and 4.5, respectively. It is beyond the scope of this study to examine whether this extent of inflation of non-fatal reported crashes in New Zealand is justified. It is possible that while there is under-reporting, the less severe injury crashes in each non-fatal injury severity category are under-reported to a greater degree than the more severe crashes. However, after the adjustment for under-reporting, the estimated crashes in each injury severity category are treated equally and multiplied by the unit crash costs in Section 3.2.4 to estimate the total social cost of crashes for the economic analysis reported here.

An adjustment for under-reporting of crashes in Australia has not been considered in Austroads reports (Thoresen et al 2003, Perovic et al 2008) and the casualty crash rates per 100 million vehicle-km used by Cameron (2003, 2004, 2011, 2012) were based on reported casualty crashes and their injury severity distribution. To facilitate a comparison and to examine the sensitivity of the economic analysis to the under-reporting adjustment, the analysis described in Sections 5.1 to 5.4 was repeated using crash rates and injury severity distributions of reported casualty crashes in New Zealand (Tables 18 and 19).

Table 18: Casualty crash rates and crash injury severity profiles based on reported crashes (2006-2010)

Road Category	Reported casualty crash rate per 100 M vehicle-km	Fatal	Serious injury	Minor injury
1. Motorways/ Expressways (divided)	12.5	1.4%	8.2%	90.5%
2. High Volume National Strategic roads	13.0	7.2%	22.6%	70.3%
3. Straight National & Regional Strategic roads	18.2	7.0%	22.5%	70.5%
4. Winding National & Regional Strategic roads	16.0	4.7%	25.6%	69.7%
5. Straight Regional Connectors & Distributors	21.5	6.6%	23.3%	70.1%
6. Winding Regional Connectors & Distributors	24.6	6.3%	25.4%	68.4%

The re-estimated optimum speeds based on reported crashes were about 5 km/h higher for cars and LCVs and generally no higher for trucks compared with those estimated using the adjusted crashes. While it is not possible to make a direct comparison for each road environment, the re-estimated optimum speeds for cars and LCVs are generally 5 to 10 km/h lower than the estimated optimum speeds for the same vehicle types in Australia, based on reported crashes and "willingness to pay" (WTP) values of crashes (Table 1). The re-estimated optimum speeds for trucks are generally at least 15 km/h less than their estimated optimum speeds in Australia based on reported crashes and WTP values.

Table 19: Injury severity profile of reported casualty crashes by vehicle type involved (2001-2010)

Road Type	Vehicle Type	Fatal (%)	Serious injury (%)	Minor injury (%)
Motorways	Passenger car	0.83	6.24	92.93
	Van or Utility (LCV)	1.21	8.57	90.22
	Truck (MCV or HCV)	2.05	12.19	85.75
Other State Highways (open road)	Passenger car	7.51	23.07	69.42
	Van or Utility (LCV)	7.88	24.92	67.19
	Truck (MCV or HCV)	13.89	25.50	60.61

Thus it can be seen that the estimation of optimum speeds in New Zealand is sensitive to the adjustments for under-reporting of non-fatal injury crashes. Differential adjustment factors are currently recommended in EEM for non-motorway rural roads related to the reported crash injury severity. Perhaps different adjustment factors are warranted for each rural road category and perhaps for crashes involving each type of vehicle.

8. DISCUSSION

The optimum speeds of trucks on rural highways are lower than those calculated for light vehicles, especially on rural motorways where 25 km/h difference has been estimated (Table 14). A lower speed limit for trucks than light vehicles would appear appropriate on divided roads such as motorways. The availability of at least two traffic lanes in each direction on these divided roads would facilitate the safe overtaking manoeuvres that would be required to a greater extent if light vehicles and trucks had differential speed limits. Lower speed limits for trucks than light vehicles are common in Europe.

The optimum speeds on rural undivided highways for trucks and light vehicles, respectively, vary by up to 15 km/h depending on the category of road. Only on the winding roads (Categories 4 and 6), where deceleration for many curves, and acceleration back to cruise speed, adds substantially to vehicle operating costs and emissions, are the optimum speeds essentially the same for light and heavy vehicles. Hence, while lower general speed limits appear appropriate for winding rural roads, there is no case for differential speed limits for trucks and light vehicles on these categories of undivided road. The need for increased opportunities for safe overtaking manoeuvres on these roads, if general speed limits were reduced, would appear no greater than currently.

However, differential speed limits do appear to be appropriate for the undivided roads in Categories 2, 3 and 5 (high volume National Strategic roads and straight 'other' State Highways). The optimum speeds for trucks and light vehicles differ by 10 to 15 km/h. If differential speed limits were to be applied in these road categories, then attention would need to be given to providing adequate overtaking opportunities, perhaps by more overtaking lanes or short sections of divided highway where the terrain allows. The influence on light vehicle speeds if truck speed limits were lower on the same undivided highways under current road conditions has not been modelled in the analysis presented here.

The findings of this report depend on the functional relationships between speed and road trauma, travel time, air pollution emissions and vehicle operating costs, the assumptions made, and the input parameters. The sensitivity of the findings to variations in these factors has been tested only to a limited extent.

9. CONCLUSIONS

Within the limits of the assumptions made and the data available for this study, a number of conclusions about optimal rural speeds and speed limits were reached.

1. The optimum speeds on Category 1 Motorways/Expressways (divided four-lane) roads would be 105 km/h for cars and light commercial vehicles and 80 km/h for trucks.[2] On other categories of (undivided) rural highways, the optimum speeds would be at most 70 km/h for trucks, but the optimum speed for cars and light commercial vehicles ranges from 85 km/h down to 65 km/h depending on the quality of the road and whether through a winding road environment.

2. Rationalisation of speed limits applicable to each class of rural highway and for each type of vehicle, making the limits consistent with the optimum speed in each case, has the potential to reduce casualty crashes and crash costs substantially. Although travel times and costs would increase, there would be a reduction in the total social costs on rural highways when all the benefits of reduced road trauma, air pollution emissions and vehicle operating costs from reduced speeds are considered.

3. The results suggest that differential speed limits would be appropriate in each category of rural highway apart from those through winding road environments (where, however, substantially reduced general speed limits for all vehicle types are appropriate). If differential speed limits were to be applied on some undivided rural highways, then attention should be given to providing adequate overtaking opportunities.

10. REFERENCES

Ahn, K, Trani, AA, Rakha, H, and Van Aerde, M (1999), 'Microscopic fuel consumption and energy emission models'. Proceedings, 78th Annual Meeting, Transportation Research Board, USA.

---

[2] This analysis was based on 435 km of Motorways primarily centred around Auckland and Wellington and divided four-lane Expressway roads primarily located in north Waikato. It is important to note that this finding is based on "free-flow" speeds where traffic volumes allow. Higher traffic volumes around major centres would be unlikely to sustain such high speeds, particularly in peak periods.

Andersson, G, Bjoerketurn, U, Bruede, U, Larsson, J, Nilsson, G, and Thulin, H (1991), 'Forecasts of traffic safety and calculated traffic safety effects for a choice of measures'. TFB and VTI forskning/research 7:6. Sweden.

Andersson, G, and Nilsson, G (1997), 'Speed management in Sweden'. Swedish National Road and Transport Research Institute (VTI), Sweden.

BITRE – Bureau of Infrastructure, Transport and Regional Economics (2009), 'Cost of road crashes in Australia 2006'. BITRE, Canberra.

BTCE – Bureau of Transport and Communications Economics (1997), 'The costs of road accidents in Victoria – 1988'. Unpublished monograph. BTCE, Canberra.

BTE – Bureau of Transport Economics (2000), 'Road crash costs in Australia'. Report 102, BTE, Canberra.

Cameron, MH (2000), 'Estimation of the optimum speed on urban residential streets'. Report to Australian Transport Safety Bureau, Canberra. Monash University Accident Research Centre.

Cameron, M.H. (2001), 'Estimation of the optimum speed on urban residential streets'. Proceedings, Road Safety Research, Policing and Education Conference, Melbourne.

Cameron, M.H. (2003), 'Potential benefits and costs of speed changes on rural roads'. Report No. CR 216, Australian Transport Safety Bureau, Canberra.

Cameron, M.H. (2004), 'Potential benefits and costs of speed changes on rural roads'. Proceedings, 2004 Road Safety Research, Policing and Education Conference, Perth.

Cameron, MH (2011), 'Rationalisation of speed limits within the Safe System approach'. Proceedings, Road Safety Research, Policing and Education Conference, Perth.

Cameron, MH (2012), 'Optimum speeds on rural roads based on "willingness to pay" values of road trauma'. Special Issue on *Safe Speeds*, Journal of Australasian College of Road Safety, Vol. 23, No. 3, August.

Cameron, MH, and Elvik, R (2010), 'Nilsson's Power Model connecting speed and road trauma: Applicability by road type and alternative models for urban roads'. Accident Analysis and Prevention, Vol. 42, No. 6.

Carlsson, G (1997), 'Cost-effectiveness of information campaigns and enforcement and the costs and benefits of speed changes'. Proceedings of European Seminar, *Cost-Effectiveness of Road Safety Work and Measures*, Luxembourg. PRI, Luxembourg.

Coesel, N, and Rietveld, P (1998), 'Time to tame our speed? Costs, benefits and acceptance of lower speed limits'. Proceedings, 9th International Conference, *Road Safety in Europe*, Cologne, Germany.

Coleman, JA, et al (1995), 'FHWA Study Tour for Speed Management and Enforcement Technology'. Federal Highway Administration, US Department of Transportation, Washington DC.

Corben, B, Newstead, S, Cameron, M, Diamantopoulou, K, and Ryan, P (1994), 'Evaluation of TAC funded accident black spot treatments: Report on Phase 2 – Evaluation system development'. Report to Transport Accident Commission. Monash University Accident Research Centre.

Cox, J (1997), 'Roads in the community. Part 1: Are they doing their job?' Austroads, Sydney.

Ding, Y. (2000), 'Quantifying the impact of traffic-related and driver-related factors on vehicle fuel consumption and emissions'. MSc thesis, Civil and Environmental Engineering, Virginia Polytechnic Institute and State University, Blacksburg VA, USA.

Elvik, R (1999), 'Cost-benefit analysis of safety measures for vulnerable and inexperienced road users: Work Package 5 of EU-Project PROMISING'. TOI, Norway.

Elvik, R. (2002), 'Optimal speed limits: Limits of optimality models'. Transportation Research Record 1818, National Research Council, Washington DC, USA.

Elvik, R., Christensen, P., and Amundsen, A. (2004), 'Speed and road accidents. An evaluation of the Power Model.' Report 740/2004, Institute of Transport Economics, Oslo, Norway.

Haworth, N, Ungers, B, Vulcan, P, and Corben, B (2001), 'Evaluation of a 50 km/h default urban speed limit for Australia'. Report to National Road Transport Commission. Monash University Accident Research Centre.

Kallberg, V-P, and Toivanen, S (1998), 'Framework for assessing the impacts of speed in road transport'. Deliverable 8, MASTER project, European Commission.

Kloeden, CN, Ponte, G, and McLean, AJ (2001), 'Travelling speed and the risk of crash involvement on rural roads'. Report CR 204, Australian Transport Safety Bureau.

Mclean, J (2001), 'Economic evaluation of road investment proposals: Improved prediction models for road crash savings'. Report AP-R184, Austroads, Sydney.

NRTC – National Road Transport Commission (1996), 'Mass Limits Review – Appendices to Technical Supplement No. 2: Road and Bridge Statistical Data Tables'. NRTC, Melbourne.

Nilsson, G. (1981), 'The effects of speed limits on traffic accidents in Sweden'. Proceedings, International Symposium, Dublin. OECD.

Nilsson, G (1984), 'Speeds, accident rates and personal injury consequences for different road types'. Rapport 277, Swedish National Road and Transport Research Institute (VTI), Sweden.

Nilsson, G. (2004), 'Traffic safety dimensions and the Power Model to describe the effect of speed on safety'. Bulletin 221, Lund Institute of Technology, Department of Technology and Society, Traffic Engineering, Lund, Sweden.

NZ MoT – New Zealand Ministry of Transport (2009), 'Safer Journeys – New Zealand's Road Safety Strategy 2010-2020'. MoT, Wellington.

NZTA – New Zealand Transport Agency (2010), 'Economic Evaluation Manual (Volume 1). NZTA, Wellington.

Peeters, PM, van Asseldonk, Y, van Binsbergen, AJ, Schoemaker, TJH, van Goevreden, CD, Vermijs, RGMM, Rietveld, P, and Rienstra, SA (1996), 'Time to tame our speed? A study of the socioeconomic cost and benefits of speed reduction of passenger cars'. Report to Research Unit for Integrated Transport Studies, Den Haag, The Netherlands.

Perovic, J, Evans, C, Lloyd, B, and Tsolakis, D (2008), 'Guide to project evaluation. Part 4: project evaluation data'. Austroads Publication No. AGPE04/08, Austroads, Sydney.

Plowden, S, and Hillman, M (1996), 'Speed control and transport policy'. Policy Studies Institute, London.

Rietveld, P, van Binsbergen, A, Schoemaker, T, and Peeters, P (1996), 'Optimum speed limits for various types of roads: a social cost-benefit analysis for the Netherlands'. Tinbergen Institute, Free University Amsterdam, The Netherlands.

Roads and Traffic Authority (2008). 'Economic valuation of safety benefits: Serious injuries – Final Summary Report'. RTA, Sydney, New South Wales.

Robertson, S, Ward, H, Marsden, G, Sandberg, U, and Hammerstrom, U (1998), 'The effect of speed on noise, vibration and emissions from vehicles'. Working paper R 1.2.1, MASTER project, European Commission.

Steadman, LA, and Bryan, RJ (1988), 'Cost of road accidents in Australia'. Occasional paper 91, Bureau of Transport and Communications Economics. AGPS, Canberra.

Taylor, MC, Baruya, A, and Kennedy, JV (2002), 'The relationship between speed and accidents on rural single-carriageway roads'. Report TRL511, Transport Research Laboratory, U.K.

Toivanen, S, and Kallberg, V-P (1998), 'Framework for assessing the impacts of speed'. Papers, Workshop II on Speed Management, Proceedings, 9th International Conference, *Road Safety in Europe*, Cologne, Germany.

Transportation Research Board (1998), 'Managing speed: review of current practices for setting and enforcing speed limits'. TRB Special Report 245, Washington DC. (http://gulliver.trb.org/publications/sr/sr254.pdf)

Ward, H, Robertson, S, and Allsop, R (1998), 'Managing speeds of traffic on European roads: Non-accident external and internal effects of vehicle use and how these depend on speed'. Papers, Workshop II on Speed Management, Proceedings, 9th International Conference, *Road Safety in Europe*, Cologne, Germany.

APPENDIX A:
MASTER FRAMEWORK FOR ANALYSIS OF IMPACTS OF A SPEED MANAGEMENT POLICY

blanco.xls

MANAGING SPEEDS OF TRAFFIC ON EUROPEAN ROADS

Application of the MASTER framework (see separate instructions) Ver. 01/99

LINK-LEVEL ANALYSIS OF THE IMPACTS OF A SPEED MANAGEMENT POLICY

Name of applier: ____________________
Institution: ____________________

1. Outlining

A. Policy test

~~A1. Length of link~~ ______ km

~~A2. Flow characteristics~~

Traffic attributes	Before policy						After policy					
						Total/Average	0	0	0	0	0	**Total/Average**
Mean speed, km/h						**#DIV/0!**						**#DIV/0!**
AADT*						**0**						**0**
Share of traffic	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Business trips, %						**#DIV/0!**						**#DIV/0!**
Pers. bus. and commuting. trips, %						**#DIV/0!**						**#DIV/0!**
Leisure trips, %						**#DIV/0!**						**#DIV/0!**

*average annual daily traffic volume, vehicles per day

B. Link/network level analysis

This workbook is best suited for link analysis. However, elastic travel demand can be assumed, for the workbook contains formulas for consumer surplus calculation.

C. Deciding on relevant impacts

- [ ] Vehicle operating costs
- [ ] Travel time
- [ ] Accidents
- [ ] Air pollution
- [ ] Noise
- [ ] Other

End of sheet

2. Measurement of impacts

D. Impact functions

D1. Vehicle operating costs

(describe here)

D2. Travel time

Function: travel time = link length/speed of traffic flow

D3a. Accidents

For example:

Injury accidents before = n_{IB} Average speed before = v_B
Injury accidents after = n_{IA} Average speed after = v_A

$$n_{IA} = (v_A/v_B)^2 * n_{IB}$$ (Andersson & Nilsson, 1997)

D3b. Accident costs

For example:

Total accident costs before = C_B, total accident costs after = C_A
k = country specific constant 1.75…2.30

$$C_A = [k*((v_A/v_B)^2-1)+1]*C_B$$ (Andersson & Nilsson, 1997)

D4. Air pollutant emission coefficients

*Emission factors**	At initial speed, g/km						At final speed, g/km					
	0	0	0	0	0	Average	0	0	0	0	0	Average
Carbon monoxide CO						**#DIV/0!**						**#DIV/0!**
Hydrocarbons HC						**#DIV/0!**						**#DIV/0!**
Oxides of nitrogen NO_x						**#DIV/0!**						**#DIV/0!**
Particles PM						**#DIV/0!**						**#DIV/0!**
Carbon dioxide CO_2						**#DIV/0!**						**#DIV/0!**

D5. Noise pollution

(specify model used here)

E. Unit prices

E1. Vehicle operating costs

	Petrol	Diesel	
Fuel price, ECU per litre			(inserting prices here is preferred to writing them in formulas with absolute numbers)

	ECU per vehicle-km											
	Before policy						After policy					
	0	0	0	0	0	**Average**	0	0	0	0	0	**Average**
Vehicle oper. costs*						**#DIV/0!**						**#DIV/0!**

**Without tax*

E2a. Time costs per hour

	ECU per hour				
Value of travel time	0	0	0	0	0
Business trips, %					
Pers. bus. and commuting. trips, %					
Leisure trips, %					
Average	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

E2b. Time costs per kilometre

	ECU per vehicle-km											
	Before policy						After policy					
	0	0	0	0	0	**Average**	0	0	0	0	0	**Average**
Time costs	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	**#DIV/0!**	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	**#DIV/0!**

E3. Total user costs
(vehicle operating+ time costs)

	ECU per vehicle-km											
	Before policy						After policy					
	0	0	0	0	0	**Average**	0	0	0	0	0	**Average**
Total user costs	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	**#DIV/0!**	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	**#DIV/0!**

E4. Accident costs

	Before	After
Accident type	**kECU/ accid.**	**kECU/ accid.**
Personal injury accident	316	#DIV/0!

E5a. Air pollution costs

Air pollutants' unit costs	**ECU/t**
Carbon monoxide CO	
Hydrocarbons HC	
Oxides of nitrogen NOx	
Particles PM	
Carbon dioxide CO2	

E5b. Noise pollution costs

Unit costs of noise pollution	**ECU/year**
Noise zone 55 to 65 dB	
Noise zone 65 to 70 dB	
Noise zone >70 dB	

F. Calculation of impacts

F1. Vehicle operating costs

	Before policy, kECU/year						After policy, kECU/year					
	0	0	0	0	0	**Total**	0	0	0	0	0	**Total**
Vehicle operating costs	0	0	0	0	0	**0**	0	0	0	0	0	**0**

F2a. Travel time

	Before policy, vehicle-hours/day					After policy, vehicle-hours/day						
	0	0	0	0	0	**Total**	0	0	0	0	0	**Total**
Total travel time on link	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	**#DIV/0!**	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	**#DIV/0!**

F2b. Travel time costs

	Before policy, kECU/year						After policy, kECU/year					
	0	0	0	0	0	**Total**	0	0	0	0	0	**Total**
Total travel time costs	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	**#DIV/0!**	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	**#DIV/0!**

F3. Consumer surplus

	Input data, before policy						Input data, after policy					
	0	0	0	0	0	**Average**	0	0	0	0	0	**Average**
Total user costs, ECU/veh.km	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	**#DIV/0!**	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Mio veh.kms/year	0	0	0	0	0	**0**	0	0	0	0	0	**0**

	Change in consumer surplus					**Total**
kECU/year	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	**#DIV/0!**

F4a. Accidents

Number of accidents per year	**Before policy**	**After policy**	**Change**	
Personal injury accident		#DIV/0!	#DIV/0!	#DIV/0!

F4b. Accident costs

	kECU/year			
Cost of accidents	**Before policy**	**After policy**	**Change**	
Personal injury accident		#DIV/0!	#DIV/0!	#DIV/0!

F5a. Air pollution

	At initial speed, t/year						At final speed, t/year					
Emissions	0	0	0	0	0	**Total**	0	0	0	0	0	**Total**
Carbon monoxide CO	0	0	0	0	0	**0**	0	0	0	0	0	**0**
Hydrocarbons HC	0	0	0	0	0	**0**	0	0	0	0	0	**0**
Oxides of nitrogen NOx	0	0	0	0	0	**0**	0	0	0	0	0	**0**
Particles PM	0	0	0	0	0	**0**	0	0	0	0	0	**0**
Carbon dioxide CO2	0	0	0	0	0	**0**	0	0	0	0	0	**0**

F5b. Air pollution costs

	At initial speed, kECU/year						At final speed, kECU/year					
Emissions	0	0	0	0	0	**Total**	0	0	0	0	0	**Total**
Carbon monoxide CO	-	-	-	-	-	-	-	-	-	-	-	-
Hydrocarbons HC	0	0	0	0	0	**0**	0	0	0	0	0	**0**
Oxides of nitrogen NOx	0	0	0	0	0	**0**	0	0	0	0	0	**0**
Particles PM	-	-	-	-	-	-	-	-	-	-	-	-
Carbon dioxide CO2	0	0	0	0	0	**0**	0	0	0	0	0	**0**
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

F5c. Noise pollution

No. of residents	**Before policy**	**After policy**	**Change**	
Noise zone 55 to 65 dB			0	#DIV/0!
Noise zone 65 to 70 dB			0	#DIV/0!
Noise zone >70 dB			0	#DIV/0!

F5d. Noise pollution costs

	kECU/ year			
	Before policy	**After policy**	**Change**	
Noise zone 55 to 65 dB	0	0	0	#DIV/0!
Noise zone 65 to 70 dB	0	0	0	#DIV/0!
Noise zone >70 dB	0	0	0	#DIV/0!
Total	**0**	**0**	**0**	**#DIV/0!**

G. Non-quantified impacts

(describe here)

H. Net impacts

H1. Physical impacts

		Before	After	Change	
Total travel time on link, hours/day		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Number of accidents per year		0.0	#DIV/0!	#DIV/0!	#DIV/0!
Emissions, t/year	Carbon monoxide CO	0	0	0	#DIV/0!
	Hydrocarbons HC	0	0	0.0	#DIV/0!
	Oxides of nitrogen NOx	0	0	0	#DIV/0!
	Particles PM	0	0	0.00	#DIV/0!
	Carbon dioxide CO2	0	0	0	#DIV/0!
Residents in area where $L_{Aeq,07\text{-}22hrs}$ > 55 dB		0	0	0	#DIV/0!

H2. Monetary impacts

kECU/year	Before	After	Change	
Consumber surplus	(N. A.)	(N. A.)		(N. A.)
Vehicle operating costs	0	0	0	#DIV/0!
Time costs	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Accident costs	0	#DIV/0!	#DIV/0!	#DIV/0!
Air pollution costs	0	0	0	#DIV/0!
Noise costs	0	0	0	#DIV/0!
Total	**#DIV/0!**	**#DIV/0!**		
Change			**#DIV/0!**	**#DIV/0!**

NB: Table H2 has two alternative appearances depending on whether the traffic volume changes:

If the **traffic volume does not change**, the difference of the sums of vehicle operating and time costs is used normally. Without an estimate of the demand curve of traffic as a function of user costs, the before and after figures for consumer surplus (CS) cannot, however, be presented. In this case, the change in consumer surplus equals the change in vehicle operating + time costs.

If the **traffic volume changes** as a result of the policy, change of the user costs cannot be used as a component of socio-economic costs of the policy. Instead, the change in consumer surplus is used. But, as stated above, the CS figures for the initial and final situation are not known, and thus the *Total* row will only include accident and environmental costs in the before and after columns. ~~The absolute figure for total change will in all cases include changes in the total costs~~, as this can always be calculated. No percent change is presented in this latter case.

I. Distribution of impacts

Affected Groups	Vehicle costs	Travel time	Accid-ents	Pollut-ion
Private motorists				
Coach passengers				
Goods traffic				
Nearby residents				
Animals crossing road				
Oth 1				
Oth 2				
Oth 3				
Oth 4				

J. Sensitivity tests

(list here)

End of sheet

APPENDIX B:
CATEGORY 1 – MOTORWAYS/EXPRESSWAYS

MANAGING SPEEDS OF TRAFFIC ON EUROPEAN ROADS

Application of the MASTER framework (see separate instructions) Ver. 01/99

LINK-LEVEL ANALYSIS OF THE IMPACTS OF A SPEED MANAGEMENT POLICY

Name of applier: Max Cameron
Institution: Monash University Accident Research Centre

1. Outlining

A. Policy test Reduction of cruise speeds to optimum speeds on Category 1 (Motorway/Expressway) roads

A1. Length of link 435.4 km

A2. Flow characteristics

Traffic attributes	**Before policy**						**After policy**					
	HCV1	HCV2	Car	LCV	MCV	**Total/ Average**	HCV1	HCV2	Car	LCV	MCV	**Total/ Average**
Cruise speed, km/h	92.5	91.5	99.1	99.1	90.7	**98.6**	80	80	105	105	80	**103.5**
Average of all speeds on link	91.5	90.4	98.2	98.2	89.9		79.5	79.4	103.7	103.6	79.5	
AADT*	538	538	22,156	2,841	538	**26,611**	538	538	22,156	2,841	538	**26,611**
Share of traffic	2%	2%	83%	11%	2%	100%	2%	2%	83%	11%	2%	100%
Business trips, %	85	85	30	55	85	**36**	85	85	30	55	85	**36**
Pers. bus. and commuting. trips,	5	5	10	5	5	**9**	5	5	10	5	5	**9**
Leisure trips, %	10	10	60	40	10	**55**	10	10	60	40	10	**55**

*average annual daily traffic volume, vehicles per day

B. Link/network level analysis

This workbook is best suited for link analysis. However, elastic travel demand can be assumed, for the workbook contains formulas for consumer surplus calculation.

C. Deciding on relevant impacts

- [x] Vehicle operating costs
- [x] Travel time
- [x] Accidents
- [x] Air pollution
- [ ] Noise
- [ ] Other

Reduction of cruise speeds to optimum speeds on Category 1 (Motorway/Expressway) roads

2. Measurement of impacts

D. Impact functions

D1. Vehicle operating costs

VOC running cost models from EEM Table A5.11 for speed and grade (adjustment for stops and curves based on EEM Tables 5.24-33)

D2. Travel time

Function: travel time = link length/free speed of traffic flow (flat straight roads only; adjustment for stops and curves based on EEM Tables 5.24-33)

D3a. Accidents

Injury accidents before = n_{IB} Average speed before = v_B

Injury accidents after = n_{IA} Average speed after = v_A

		Exponent	Value	
Fatal accidents	$n_{IA} = (v_A/v_B)F * n_{IB}$	F	4.1	Rural highway/freeway exponent estimates
Serious injury accidents	$n_{IA} = (v_A/v_B)S * n_{IB}$	S	2.6	from Cameron and Elvik (2010), Table 8
Other injury accidents	$n_{IA} = (v_A/v_B)O * n_{IB}$	O	1.1	

Base emissions functions (g/vkt) from EEM table in Appendix A9.3

Source:		Carbon monoxide CO			Oxides of nitrogen NO_x			Particles PO10		
MASTER Working		A	B	C	A	B	C	A	B	C
Paper R1.2.1,	LV	0.00360	-0.545	25.5	0.000246	-0.0287	1.67	#######	-0.00342	0.153
App. D, p. D-6	HV	0.000647	-0.11	7.31	0.002040	-0.275	17.4	0.000382	-0.0455	2.65

D4. Air pollutant emission coefficients

Cruise speed, km/h	92.5	91.5	99.1	99.1	90.7		80	80	105	105	80	
*Emission factors**	**At initial speed, g/km**						**At final speed, g/km**					
	HCV1	HCV2	Car	LCV	MCV	Average	HCV1	HCV2	Car	LCV	MCV	Average
Carbon monoxide CO	3.10	3.09	8.27	8.27	3.08	7.96	2.90	2.90	10.10	10.10	2.90	9.66
Hydrocarbons HC	0.43	0.43	0.47	0.47	0.42	0.47	0.37	0.37	0.51	0.51	0.37	0.50
Oxides of nitrogen NO_x	11.03	10.91	1.52	1.52	10.82	2.09	9.31	9.31	1.76	1.76	9.31	2.22
Particles PM	1.84	1.81	0.06	0.06	1.79	0.166	1.52	1.52	0.07	0.07	1.52	0.160
Carbon dioxide CO_2	2224.8	4805.7	234.5	272.0	1006.3	386.8	2083.5	4595.1	241.5	283.4	950.1	385.5

Emission coefficients for HC not available by vehicle type, only for mix of traffic close to mix outlined here

CO2: EEM function of VOC from row 59 + row 70

CO, Nox, PM: EEM functions with Ding adjustment factors

HC: g/km from 2000 AADT

Flat road 80 kmh	90 kmh
678	739

Adjustment factors for increased emissions due to stops and sharp curves (less than 200m radius) on road

	At initial speed, g/km						**At final speed, g/km**					
	HCV1	HCV2	Car	LCV	MCV		HCV1	HCV2	Car	LCV	MCV	
CO	1.161	1.161	1.208	1.208	1.161		1.096	1.096	1.268	1.268	1.096	
HC	1.138	1.138	1.178	1.178	1.138		1.083	1.083	1.226	1.226	1.083	
NOx	1.171	1.171	1.222	1.222	1.171		1.101	1.101	1.286	1.286	1.101	
PM	1.075	1.075	1.098	1.098	1.075		1.042	1.042	1.127	1.127	1.042	
CO2	Adjusted through VOC adjustments for stops and curves											

D5. Noise pollution

No impact function available; noise pollution assumed small because of negligible human population living in vicinity of rural roads considered

E. Unit prices

	Time cost	VOC	Crash cost	$AUS to $NZ
Base year to 2009				
Update factor	1.220	1.000	1.140	1.25

E1. Vehicle operating costs

Source: EEM Table A5.11

	a	-75.602	-263.900	24.616	15.852	20.230		-75.602	-263.900	24.616	15.852	20.230	
	c	263.07	469.66	43.489	64.641	87.808		263.07	469.66	43.489	64.641	87.808	
	e	-101.34	-159.79	-21.157	-30.064	-39.668		-101.34	-159.79	-21.157	-30.064	-39.668	
	h	11.615	17.174	2.5663	3.6463	4.8935		11.615	17.174	2.5663	3.6463	4.8935	
	Zero grade VOC (cents/km)	116.08	180.05	26.73	31.89	58.22		108.57	170.95	27.45	33.08	55.06	
		$ per vehicle-km											
		Before policy						**After policy**					
		HCV1	HCV2	Car	LCV	MCV	**Average**	HCV1	HCV2	Car	LCV	MCV	**Average**
	Vehicle Operating Costs (VOC)	1.373	2.959	0.259	0.300	0.623	**0.348**	1.295	2.856	0.267	0.312	0.591	**0.351**
100	b	82.435	2722.4	-44.832	-109.65	-70.181		82.435	2722.4	-44.832	-109.65	-70.181	
####	d	9566.1	15069	-445.63	-118.58	2731.4		9566.1	15069	-445.63	-118.58	2731.4	
100	f	-65.136	-1446.2	38.558	68.678	55.741		-65.136	-1446.2	38.558	68.678	55.741	
####	g	-608.65	-1306	17.595	12.105	-165.84		-608.65	-1306	17.595	12.105	-165.84	
1000	i	-48.388	1796.9	-61.237	-99.936	-147.07		-48.388	1796.9	-61.237	-99.936	-147.07	
1000	j	171.01	488.06	12.523	15.75	58.615		171.01	488.06	12.523	15.75	58.615	
Rolling:	Additional VOC for GR4-6	35.84	183.91	-1.22	-2.77	7.38		35.38	182.07	-1.21	-2.76	7.29	
Mount'ous:	Additional VOC for GR7-11	99.30	421.75	-1.22	-3.04	24.64		97.45	416.23	-1.17	-2.98	24.14	
"Flat":	Additional VOC for GR1-3	4.14	39.58	-0.35	-0.90	0.14		4.20	39.12	-0.36	-0.91	0.20	
	Additional VOC for stops/curves	0.018	0.045	0.001	0.002	0.006	**0.002**	0.007	0.016	0.002	0.003	0.002	**0.002**
	(added in row 118, not row 59)	1.28%	1.50%	0.41%	0.59%	0.89%	**0.70%**	0.52%	0.57%	0.59%	0.81%	0.40%	**0.60%**

Zero grade VOC plus additional VOC for grade (on % vkt applicable)
No update factor applied (because 1 for VOC)

Category 1 roads
% of VKT in terrain

GR	HV	LV
5	45.49%	46.78%
9	2.78%	3.04%
2	51.73%	50.18%

E2a. Time costs per hour

Value of travel time	**$ per hour**				
	HCV1	HCV2	Car	LCV	MCV
Business trips, %	55.2	68.6	48.2	49.2	41.8
Pers. bus. and commuting. trips,	12.4	12.4	14.5	14.5	12.4
Leisure trips, %	11.0	11.0	12.9	12.9	11.0
Average	**48.6**	**60.0**	**23.6**	**32.9**	**37.2**

Travel time values at June 2002 from EEM Tables A4.1-2 and vehicle occupancy rates from EEM Table A2.5

E2b. Time costs per kilometre

	$ per vehicle-km											
	Before policy						**After policy**					
	HCV1	HCV2	Car	LCV	MCV	**Average**	HCV1	HCV2	Car	LCV	MCV	**Average**
Time costs	0.531	0.664	0.241	0.336	0.414	**0.2687**	0.612	0.756	0.228	0.318	0.468	**0.2608**

E3. Total user costs
(vehicle operating+ time costs)

	$ per vehicle-km											
	Before policy						**After policy**					
	HCV1	HCV2	Car	LCV	MCV	**Average**	HCV1	HCV2	Car	LCV	MCV	**Average**
Total user costs	1.904	3.623	0.500	0.636	1.037	**0.617**	1.907	3.612	0.495	0.630	1.059	**0.612**

E4. Accident costs

Accident type	**kA$/ accid.**
Fatal accident	4332
Serious injury accident	461.7
Other injury accident	27.4
Personal injury accident (av.)	

Unit costs of reported crashes in 100 km/h speed limit areas from EEM Tables A6.21(e)-(g)

E5a. Air pollution costs

Air pollutants' unit costs	$/t	
Carbon monoxide CO	0.038	
Hydrocarbons HC	12.0	
Oxides of nitrogen NOx	23.9	
Particles PM	3804	
Carbon dioxide CO2	40.0	Unit cost specified in EEM Section A9.7

Other costs based on unit costs in Table 5.3 in Austroads AGPE04/08 (in NZ$), but only 1% reflecting emissions in rural area

E5b. Noise pollution costs

Unit costs of noise pollution	$/year
Noise zone 55 to 65 dB	
Noise zone 65 to 70 dB	
Noise zone >70 dB	

Treated as zero in rural areas in Table 5.1 of Austroads AGPE04/08

Base VOC with additional for grade on % of vkt applicable on link [calculated at row 59]

Additional VOC for stops and curves [calculates total additional below and converts to $ per veh-km in row 70]

Cruise speed, km/h	92.5	91.5	99.1	99.1	90.7	80	80	105	105	80

F. Calculation of impacts

F1. Vehicle operating costs

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Vehicle operating costs	118,888	256,807	917,383	136,442	53,773	**1,483,293**	111,337	245,556	944,633	142,163	50,774	**1,494,464**

Additional VOC and travel time for stops and slowing for curves

Category 1 roads (Factors for density of stops and curves per 100 km)

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
additional	1,508	3,805	3,736	796	476	**10,322**	575	1,391	5,542	1,149	203	**8,860**
% added	1.28%	1.50%	0.41%	0.59%	0.89%	0.70%	0.52%	0.57%	0.59%	0.81%	0.40%	0.60%

F2a. Travel time

	Before policy, vehicle-hours/day						After policy, vehicle-hours/day					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Total travel time on link	2,560	2,591	98,190	12,598	2,606	**118,546**	2,948	2,950	92,987	11,935	2,945	**113,764**

	Before policy, vehicle-hours/day						After policy, vehicle-hours/day					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
additional	28	31	846	118	23	**1,046**	19	22	1,113	156	17	**1,326**
@free speed	2,532	2,560	97,345	12,480	2,583	**117,500**	2,928	2,928	91,875	11,779	2,928	**112,438**
% added	1.10%	1.20%	0.87%	0.95%	0.90%	0.89%	0.66%	0.74%	1.21%	1.32%	0.58%	1.18%

F2b. Travel time costs

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Total travel time costs	45,442	56,770	847,178	151,458	35,405	**1,136,251**	52,316	64,641	802,287	143,479	40,009	**1,102,732**

Base travel time = length/cruise speed*AADT

Additional travel time calculated above (for total stops and curves on link)

Total travel time [use to calculate average speed on link: row 24 in Outlining]

F3. Consumer surplus

	Input data, before policy						Input data, after policy					
	HCV1	HCV2	Car	LCV	MCV	**Average**	HCV1	HCV2	Car	LCV	MCV	**Average**
Total user costs, $/veh.km	1.904	3.623	0.500	0.636	1.037	**0.617**	1.907	3.612	0.495	0.630	1.059	0.612
Mio veh.kms/year	86	86	3,521	451	86	**4,229**	86	86	3,521	451	86	**4,229**

	Change in consumer surplus					**Total**
k$/year	255	-965	-19445	-2611	1879	**-20887**

F4a. Casualty accident rates

	Before policy, crashes/year						After policy, crashes/year						
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**	
Crash rate per million VKT	0.236	0.236	0.236	0.236	0.236	0.236	0.196	0.198	0.253	0.254	0.201	0.250	**Category 1 roads** adjusted injury crash rate/100M vkt from Summary col. AL

F4b. Casualty accident severity

	Before policy, crashes/year						After policy, crashes/year						
	HCV1	HCV2	Car	LCV	MCV	**Average**	HCV1	HCV2	Car	LCV	MCV	**Average**	**Motorway roads (Cat 1)**
Fatal (%)	1.09	1.09	0.44	0.64	1.09	0.50	0.73	0.75	0.52	0.75	0.77	0.55	**Crash injury severity of adjusted injury crashes**
Serious injury (%)	12.31	12.31	6.27	8.62	12.31	6.88	10.19	10.33	6.79	9.31	10.46	7.23	**by vehicle type involved (car, LCV, truck)**
Minor injury (%)	86.60	86.60	93.29	90.74	86.60	92.62	89.09	88.92	92.69	89.93	88.78	92.21	from email from Fergus Tate 12 June 2012

F4c. Accidents

	Before policy, crashes/year						After policy, crashes/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Fatal accident	0.2	0.2	3.6	0.7	0.2	**5.0**	0.1	0.1	4.6	0.9	0.1	**5.9**
Serious injury accident	2.5	2.5	52.1	9.2	2.5	**68.8**	1.7	1.8	60.6	10.7	1.8	**76.5**
Minor injury accident	17.5	17.5	776.0	96.8	17.5	**925.2**	14.9	15.1	827.0	103.1	15.2	**975.3**
Total casualty accidents	20.2	20.2	831.8	106.6	20.2	**999.0**	16.7	17.0	892.2	114.7	17.2	**1,057.7**

F4d. Accident costs

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Fatal accident	956	956	15,792	2,958	956	**21,616**	527	551	20,017	3,750	571	**25,415**
Serious injury accident	1,148	1,148	24,068	4,243	1,148	**31,755**	787	810	27,973	4,931	828	**35,329**
Minor injury accident	479	479	21,231	2,647	479	**25,314**	408	413	22,626	2,821	417	**26,685**
Total casualty accidents	2,582	2,582	61,090	9,849	2,582	**78,685**	1,722	1,773	70,615	11,502	1,816	**87,429**

F5a. Air pollution

	At initial speed, t/year						At final speed, t/year					
Emissions	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Carbon monoxide CO	265	264	29,125	3,734	264	**33,652**	248	248	35554	4558	248	**40,857**
Hydrocarbons HC	37	36	1,647	211	36	**1,968**	31	31	1793	230	31	**2,117**
Oxides of nitrogen NOx	943	933	5,343	685	925	**8,828**	796	796	6198	795	796	**9,381**
Particles PM	157	155	212	27	153	**704**	130	130	254	33	130	**675**
Carbon dioxide CO2	190,222	410,891	825,645	122,798	86,037	**1,635,592**	178,139	392,890	850,170	127,947	81,238	**1,630,384**

F5b. Air pollution costs

	At initial speed, k$/year						At final speed, k$/year					
Emissions	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Carbon monoxide CO	0.0	0.0	1.1	0.1	0.0	**1.3**	0.0	0.0	1.3	0.2	0.0	**1.5**
Hydrocarbons HC	0	0	20	3	0	**24**	0	0	21	3	0	**25**
Oxides of nitrogen NOx	23	22	128	16	22	**211**	19	19	148	19	19	**224**
Particles PM	598	589	805	103	582	**2,677**	493	493	967	124	493	**2,569**
Carbon dioxide CO2	7,609	16,436	33,026	4,912	3,441	**65,424**	7,126	15,716	34,007	5,118	3,250	**65,215**
Total	**8,230**	**17,047**	**33,979**	**5,034**	**4,046**	**68,336**	**7,638**	**16,228**	**35,144**	**5,264**	**3,762**	**68,036**

F5c. Noise pollution

No. of residents	**Before policy**	**After policy**	**Change**	
Noise zone 55 to 65 dB			0	#DIV/0!
Noise zone 65 to 70 dB			0	#DIV/0!
Noise zone >70 dB			0	#DIV/0!

F5d. Noise pollution costs

	k$/ year			
	Before policy	**After policy**	**Change**	
Noise zone 55 to 65 dB	0	0	0	#DIV/0!
Noise zone 65 to 70 dB	0	0	0	#DIV/0!
Noise zone >70 dB	0	0	0	#DIV/0!
Total	**0**	**0**	**0**	**#DIV/0!**

G. Non-quantified impacts

Noise pollution

Summary of quantified impacts

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Total monetary impact	175,142	333,206	1,859,630	302,783	95,806	**2,766,566**	173,013	328,198	1,852,680	302,408	96,362	**2,752,661**

MANAGING SPEEDS OF TRAFFIC ON EUROPEAN ROADS

Application of the MASTER framework

Ver. 01/99

Reduction of cruise speeds to optimum speeds on Category 1 (Motorway/Expressway) roads

H. Net impacts

	Cruise Speed (km/h)	
Trucks (LCV I)	**92.5**	**80**
Cars	**99.1**	**105**

Average speed on link (km/h)	Before	After
Trucks (LCV I)	**91.5**	**79.5**
Cars	**98.2**	**103.7**

H1. Physical impacts

		Before	After	Change	
Total travel time on link, hours/day		118,546	113,764	-4,781	-4.0 %
Number of Crashes per year		999.0	1,057.7	58.7	5.9%
Emissions, t/year	Carbon monoxide CO	33652	40857	7205	21.4 %
	Hydrocarbons HC	1968	2117	149.7	7.6 %
	Oxides of nitrogen NOx	8828	9381	552	6.3 %
	Particles PM	703.7	675.5	-28.26	-4.0 %
	Carbon dioxide CO2	1635592	1630384	-5207	-0.3 %
Residents in area where $L_{Aeq,07-22hrs}$ > 55 d		0	0	0	

Increase/vehicle/100km (mins.) Trucks: **9.9** Cars: **-3.2**

Saving p.a. Fatal: **-0.9** Serious Inj: **-7.7** Other Inj: **-50.1**

H2. Monetary impacts

k$/year	**Before**	**After**	**Change**	
Consumer surplus	(N. A.)	(N. A.)		(N. A.)
Vehicle operating costs	1,483,293	1,494,464	11170	0.8 %
Time costs	1,136,251	1,102,732	-33519	-2.9 %
Crash costs	78,685	87,429	8,744	11.1%
Air pollution costs	68,336	68,036	-301	-0.4 %
Noise costs (not valued)	0	0	0	
Total	**2,766,566**	**2,752,661**		
Change			**-13,905**	**-0.5 %**

H3. Summary of monetary impacts for each cruise speed

kA$/year km/h	70	75	80	85	90	95	100	105	110	115	120	125	130
Consumer surplus	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)
Vehicle operating costs	1,337,579	1,355,497	1,377,788	1,403,891	1,434,710	1,468,903	1,506,467	1,546,192	1,587,810	1,631,088	1,675,822	1,721,837	1,768,978
Time costs	1,584,812	1,479,834	1,388,020	1,307,146	1,235,597	1,172,518	1,116,894	1,066,918	1,021,814	980,937	943,748	909,791	878,678
Crash costs	36,001	41,745	48,199	55,434	63,525	72,549	82,589	93,733	106,070	119,696	134,710	151,216	169,320
Air pollution costs	61,179	62,098	63,239	64,587	66,221	68,055	70,097	72,190	74,407	76,739	79,177	81,715	84,346
Noise costs (not valued)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**3,019,570**	**2,939,175**	**2,877,246**	**2,831,058**	**2,800,053**	**2,782,025**	**2,776,047**	**2,779,034**	**2,790,102**	**2,808,460**	**2,833,458**	**2,864,559**	**2,901,322**
of which:													
Heavy vehicles	603,001	599,062	**597,573**	598,214	602,277	608,105	615,398	623,946	633,692	644,548	656,441	669,313	683,118
Cars & light comm. vehs.	2,416,569	2,340,113	2,279,673	2,232,844	2,197,776	2,173,920	2,160,649	**2,155,088**	2,156,410	2,163,912	2,177,017	2,195,246	2,218,204

H4. Monetary impacts for cars and LCVs at each cruise speed

kA$/year km/h	70	75	80	85	90	95	100	105	110	115	120	125	130
Consumer surplus	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)
Vehicle operating costs	943,993	955,259	970,121	988,099	1,008,831	1,032,330	1,058,707	1,086,797	1,116,365	1,147,211	1,179,159	1,212,055	1,245,764
Time costs	1,405,705	1,312,545	1,231,053	1,159,261	1,095,628	1,039,525	990,138	945,766	905,720	869,429	836,413	806,268	778,649
Crash costs	32,265	37,276	42,887	49,158	56,149	63,927	72,559	82,118	92,678	104,320	117,125	131,178	146,570
Air pollution costs	34,605	35,033	35,612	36,326	37,168	38,138	39,246	40,408	41,646	42,952	44,320	45,745	47,221
Noise costs (not valued)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**2,416,569**	**2,340,113**	**2,279,673**	**2,232,844**	**2,197,776**	**2,173,920**	**2,160,649**	**2,155,088**	**2,156,410**	**2,163,912**	**2,177,017**	**2,195,246**	**2,218,204**

H5. Monetary impacts for heavy vehicles at each cruise speed

kA$/year km/h	70	75	80	85	90	95	100	105	110	115	120	125	130
Consumer surplus	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)
Vehicle operating costs	393,585	400,239	407,667	415,792	425,879	436,573	447,760	459,396	471,445	483,876	496,663	509,782	523,214
Time costs	179,106	167,289	156,966	147,885	139,969	132,993	126,756	121,152	116,094	111,509	107,336	103,523	100,028
Crash costs	3,736	4,469	5,312	6,276	7,375	8,622	10,031	11,615	13,392	15,376	17,586	20,038	22,751
Air pollution costs	26,573	27,065	27,628	28,261	29,053	29,917	30,851	31,782	32,761	33,787	34,857	35,970	37,125
Noise costs (not valued)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**603,001**	**599,062**	**597,573**	**598,214**	**602,277**	**608,105**	**615,398**	**623,946**	**633,692**	**644,548**	**656,441**	**669,313**	**683,118**

APPENDIX C:
CATEGORY 2 - HIGH VOLUME NATIONAL STRATEGIC ROADS

MANAGING SPEEDS OF TRAFFIC ON EUROPEAN ROADS

Application of the MASTER framework (see separate instructions) Ver. 01/99

LINK-LEVEL ANALYSIS OF THE IMPACTS OF A SPEED MANAGEMENT POLICY

Name of applier: Max Cameron
Institution: Monash University Accident Research Centre

1. Outlining

A. Policy test Reduction of cruise speeds to optimum speeds on Category 2 (High Volume National Strategic) roads

A1. Length of link 371.0 km

A2. Flow characteristics

Traffic attributes	Before policy						After policy					
	HCV1	HCV2	Car	LCV	MCV	**Total/Average**	HCV1	HCV2	Car	LCV	MCV	**Total/Average**
Cruise speed, km/h	87.7	86.9	93.9	93.9	86.1	**93.2**	70	70	85	85	70	**83.4**
Average of all speeds on link	85.7	84.7	91.9	91.8	84.5		69.2	69.1	83.8	83.7	69.3	
AADT*	448	448	10,169	1,304	448	**12,817**	448	448	10,169	1,304	448	**12,817**
Share of traffic	3%	3%	79%	10%	3%	100%	3%	3%	79%	10%	3%	100%
Business trips, %	85	85	30	55	85	**38**	85	85	30	55	85	**38**
Pers. bus. and commuting. trips,	5	5	10	5	5	**9**	5	5	10	5	5	**9**
Leisure trips, %	10	10	60	40	10	**53**	10	10	60	40	10	**53**

*average annual daily traffic volume, vehicles per day

B. Link/network level analysis

This workbook is best suited for link analysis. However, elastic travel demand can be assumed, for the workbook contains formulas for consumer surplus calculation.

C. Deciding on relevant impacts

- [x] Vehicle operating costs
- [x] Travel time
- [x] Accidents
- [x] Air pollution
- [ ] Noise
- [ ] Other

Reduction of cruise speeds to optimum speeds on Category 2 (High Volume National Strategic) roads

2. Measurement of impacts

D. Impact functions

D1. Vehicle operating costs

VOC running cost models from EEM Table A5.11 for speed and grade (adjustment for stops and curves based on EEM Tables 5.24-33)

D2. Travel time

Function: travel time = link length/free speed of traffic flow (flat straight roads only; adjustment for stops and curves based on EEM Tables 5.24-33)

D3a. Accidents

Injury accidents before = n_{IB} Average speed before = v_B

Injury accidents after = n_{IA} Average speed after = v_A

		Exponent	Value	
Fatal accidents	$n_{IA} = (v_A/v_B)F * n_{IB}$	F	4.1	Rural highway/freeway exponent estimates
Serious injury accidents	$n_{IA} = (v_A/v_B)S * n_{IB}$	S	2.6	from Cameron and Elvik (2010), Table 8
Other injury accidents	$n_{IA} = (v_A/v_B)O * n_{IB}$	O	1.1	

Base emissions functions (g/vkt) from EEM table in Appendix A9.3

Source:		Carbon monoxide CO			Oxides of nitrogen NO_x			Particles PO10		
MASTER Working		A	B	C	A	B	C	A	B	C
Paper R1.2.1,	LV	0.00360	-0.545	25.5	0.000246	-0.0287	1.67	#######	-0.00342	0.153
App. D, p. D-6	HV	0.000647	-0.11	7.31	0.002040	-0.275	17.4	0.000382	-0.0455	2.65

D4. Air pollutant emission coefficients

Cruise speed, km/h	87.7	86.9	93.9	93.9	86.1		70	70	85	85	70	
*Emission factors**	At initial speed, g/km						At final speed, g/km					
	HCV1	HCV2	Car	LCV	MCV	Average	HCV1	HCV2	Car	LCV	MCV	Average
Carbon monoxide CO	2.96	2.96	7.13	7.13	2.96	6.69	2.91	2.91	5.82	5.82	2.91	5.52
Hydrocarbons HC	0.40	0.40	0.44	0.44	0.40	0.43	0.32	0.32	0.39	0.39	0.32	0.38
Oxides of nitrogen NO_x	10.14	10.06	1.36	1.36	9.99	2.27	8.56	8.56	1.14	1.14	8.56	1.92
Particles PM	1.69	1.67	0.05	0.05	1.65	0.222	1.36	1.36	0.04	0.04	1.36	0.180
Carbon dioxide CO_2	2321.4	5286.1	229.6	263.5	1022.3	510.6	2112.4	4922.3	220.9	248.2	938.2	479.2

Emission coefficients for HC not available by vehicle type, only for mix of traffic close to mix outlined here

CO2: EEM function of VOC from row 59 + row 70

CO, Nox, PM: EEM functions with Ding adjustment factors

HC: g/km from 2000 AADT

Flat road 80 kmh	Flat road 90 kmh
678	739

Adjustment factors for increased emissions due to stops and sharp curves (less than 200m radius) on road

	At initial speed, g/km						At final speed, g/km					
	HCV1	HCV2	Car	LCV	MCV		HCV1	HCV2	Car	LCV	MCV	
CO	1.123	1.123	1.175	1.175	1.123		1.048	1.048	1.123	1.123	1.048	
HC	1.105	1.105	1.149	1.149	1.105		1.042	1.042	1.105	1.105	1.042	
NOx	1.130	1.130	1.186	1.186	1.130		1.051	1.051	1.130	1.130	1.051	
PM	1.057	1.057	1.084	1.084	1.057		1.018	1.018	1.057	1.057	1.018	
CO2	Adjusted through VOC adjustments for stops and curves											

D5. Noise pollution

No impact function available; noise pollution assumed small because of negligible human population living in vicinity of rural roads considered

E. Unit prices

	Time cost	VOC	Crash cost	$AUS to $NZ
Base year to 2009 Update factor	1.220	1.000	1.140	1.25

E1. Vehicle operating costs

		HCV1	HCV2	Car	LCV	MCV		HCV1	HCV2	Car	LCV	MCV		
	a	-75.602	-263.900	24.616	15.852	20.230		-75.602	-263.900	24.616	15.852	20.230		
	c	263.07	469.66	43.489	64.641	87.808		263.07	469.66	43.489	64.641	87.808		
	e	-101.34	-159.79	-21.157	-30.064	-39.668		-101.34	-159.79	-21.157	-30.064	-39.668		
	h	11.615	17.174	2.5663	3.6463	4.8935		11.615	17.174	2.5663	3.6463	4.8935		
Zero grade VOC (cents/km)		113.06	176.25	26.14	30.90	56.81		103.58	164.26	25.27	29.38	52.54		
		$ per vehicle-km												
		Before policy						**After policy**						
		HCV1	HCV2	Car	LCV	MCV	**Average**	HCV1	HCV2	Car	LCV	MCV	**Average**	
Vehicle Operating Costs (VOC)		1.407	3.189	0.253	0.289	0.625	**0.412**	1.307	3.045	0.244	0.273	0.582	**0.394**	
100	b	82.435	2722.4	-44.832	-109.65	-70.181		82.435	2722.4	-44.832	-109.65	-70.181		
####	d	9566.1	15069	-445.63	-118.58	2731.4		9566.1	15069	-445.63	-118.58	2731.4		
100	f	-65.136	-1446.2	38.558	68.678	55.741		-65.136	-1446.2	38.558	68.678	55.741		
####	g	-608.65	-1306	17.595	12.105	-165.84		-608.65	-1306	17.595	12.105	-165.84		
1000	i	-48.388	1796.9	-61.237	-99.936	-147.07		-48.388	1796.9	-61.237	-99.936	-147.07		
1000	j	171.01	488.06	12.523	15.75	58.615		171.01	488.06	12.523	15.75	58.615		GR
Rolling: Additional VOC for GR4-6		35.67	183.19	-1.23	-2.78	7.34		34.95	180.30	-1.24	-2.80	7.19		5
Mount'ous: Additional VOC for GR7-11		98.62	419.62	-1.27	-3.09	24.44		95.74	410.81	-1.35	-3.20	23.60		9
"Flat": Additional VOC for GR1-3		4.17	39.40	-0.35	-0.89	0.16		4.25	38.72	-0.33	-0.87	0.27		2
Additional VOC for stops/curves		0.044	0.115	0.002	0.004	0.014	**0.008**	0.013	0.032	0.002	0.003	0.005	**0.003**	
(added in row 118, not row 59)		3.11%	3.59%	0.99%	1.47%	2.17%	**2.04%**	1.03%	1.04%	0.67%	0.94%	0.81%	**0.84%**	

Source: EEM Table A5.11

Zero grade VOC plus additional VOC for grade (on % vkt applicable)
No update factor applied (because 1 for VOC)

Category 2 roads
% of VKT in terrain

HV	LV
51.25%	52.75%
7.78%	7.47%
40.97%	39.78%

E2a. Time costs per hour

Value of travel time	**$ per hour**				
	HCV1	HCV2	Car	LCV	MCV
Business trips, %	55.2	68.6	48.2	49.2	41.8
Pers. bus. and commuting. trips,	12.4	12.4	14.5	14.5	12.4
Leisure trips, %	11.0	11.0	12.9	12.9	11.0
Average	**48.6**	**60.0**	**23.6**	**32.9**	**37.2**

Travel time values at June 2002 from EEM Tables A4.1-2 and vehicle occupancy rates from EEM Table A2.5

E2b. Time costs per kilometre

	$ per vehicle-km											
	Before policy						**After policy**					
	HCV1	HCV2	Car	LCV	MCV	**Average**	HCV1	HCV2	Car	LCV	MCV	**Average**
Time costs	0.568	0.708	0.257	0.359	0.441	**0.3005**	0.703	0.869	0.282	0.394	0.537	**0.3375**

E3. Total user costs
(vehicle operating+ time costs)

	$ per vehicle-km											
	Before policy						**After policy**					
	HCV1	HCV2	Car	LCV	MCV	**Average**	HCV1	HCV2	Car	LCV	MCV	**Average**
Total user costs	1.975	3.898	0.510	0.647	1.066	**0.713**	2.009	3.913	0.526	0.667	1.119	**0.731**

E4. Accident costs

Accident type	**kA$/ accid.**
Fatal accident	4332
Serious injury accident	461.7
Other injury accident	27.4
Personal injury accident (av.)	

Unit costs of reported crashes in 100 km/h speed limit areas from EEM Tables A6.21(e)-(g)

E5a. Air pollution costs

Air pollutants' unit costs	$/t	
Carbon monoxide CO	0.038	
Hydrocarbons HC	12.0	
Oxides of nitrogen NOx	23.9	
Particles PM	3804	
Carbon dioxide CO2	40.0	Unit cost specified in EEM Section A9.7

Other costs based on unit costs in Table 5.3 in Austroads AGPE04/08 (in NZ$), but only 1% reflecting emissions in rural area

E5b. Noise pollution costs

Unit costs of noise pollution	$/year
Noise zone 55 to 65 dB	
Noise zone 65 to 70 dB	
Noise zone >70 dB	

Treated as zero in rural areas in Table 5.1 of Austroads AGPE04/08

Base VOC with additional for grade on % of vkt applicable on link [calculated at row 59]
Additional VOC for stops and curves [calculates total additional below and converts to $ per veh-km in row 70]

Cruise speed, km/h	87.7	86.9	93.9	93.9	86.1		70	70	85	85	70

F. Calculation of impacts

F1. Vehicle operating costs

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Vehicle operating costs	88,005	200,397	351,365	51,684	38,757	**730,208**	80,081	186,607	337,994	48,679	35,566	**688,927**

Additional VOC and travel time for stops and slowing for curves

Category 2 roads (Factors for density of stops and curves per 100 km)

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
additional	2,653	6,954	3,430	749	822	**14,608**	816	1,925	2,234	454	284	**5,713**
% added	3.11%	3.59%	0.99%	1.47%	2.17%	2.04%	1.03%	1.04%	0.67%	0.94%	0.81%	0.84%

F2a. Travel time

	Before policy, vehicle-hours/day						After policy, vehicle-hours/day					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Total travel time on link	1,940	1,961	41,037	5,271	1,967	**52,175**	2,401	2,405	45,021	5,779	2,398	**58,004**

	Before policy, vehicle-hours/day						After policy, vehicle-hours/day					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
additional	45	49	858	120	37	**1,108**	27	31	635	89	24	**805**
@free speed	1,895	1,912	40,179	5,151	1,930	**51,067**	2,374	2,374	44,386	5,690	2,374	**57,198**
% added	2.35%	2.55%	2.13%	2.32%	1.90%	2.17%	1.15%	1.29%	1.43%	1.56%	0.99%	1.41%

F2b. Travel time costs

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Total travel time costs	34,425	42,974	354,061	63,367	26,721	**521,547**	42,623	52,690	388,436	69,477	32,573	**585,799**

Base travel time = length/cruise speed*AADT
Additional travel time calculated above (for total stops and curves on link)
Total travel time [use to calculate average speed on link: row 24 in Outlining]

F3. Consumer surplus

	Input data, before policy						Input data, after policy					
	HCV1	HCV2	Car	LCV	MCV	Average	HCV1	HCV2	Car	LCV	MCV	Average
Total user costs, $/veh.km	1.975	3.898	0.510	0.647	1.066	**0.713**	2.009	3.913	0.526	0.667	1.119	0.731
Mio veh.kms/year	61	61	1,377	177	61	**1,736**	61	61	1,377	177	61	**1,736**

	Change in consumer surplus					Total
k$/year	2110	955	22202	3400	3199	**31866**

F4a. Casualty accident rates

	Before policy, crashes/year						After policy, crashes/year						
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**	
Crash rate per million VKT	0.477	0.477	0.477	0.477	0.477	0.477	0.349	0.353	0.418	0.417	0.358	0.411	**Category 2 roads** adjusted injury crash rate/100M vkt from Summary col. AL

F4b. Casualty accident severity

	Before policy, crashes/year						After policy, crashes/year						
	HCV1	HCV2	Car	LCV	MCV	Average	HCV1	HCV2	Car	LCV	MCV	Average	**Open road State Highway**
Fatal (%)	4.15	4.15	2.06	2.20	4.15	2.30	2.25	2.30	1.57	1.68	2.36	1.64	**Crash injury severity of adjusted injury crashes**
Serious injury (%)	14.46	14.46	12.05	13.24	14.46	12.42	10.99	11.12	10.61	11.69	11.25	10.77	**by vehicle type involved (car, LCV, truck)**
Minor injury (%)	81.39	81.39	85.89	84.55	81.39	85.28	86.76	86.57	87.82	86.64	86.38	87.59	from email from Fergus Tate 12 June 2012

NOTE: Lower injury severity on Motorways (Cat 1)

F4c. Accidents

	Before policy, crashes/year						After policy, crashes/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Fatal accident	1.2	1.2	13.6	1.9	1.2	**19.0**	0.5	0.5	9.0	1.2	0.5	**11.7**
Serious injury accident	4.2	4.2	79.1	11.1	4.2	**102.8**	2.3	2.4	61.1	8.6	2.4	**76.8**
Minor injury accident	23.5	23.5	564.0	71.2	23.5	**705.9**	18.4	18.6	505.5	63.8	18.7	**625.0**
Total casualty accidents	28.9	28.9	656.7	84.2	28.9	**827.7**	21.2	21.4	575.6	73.6	21.7	**713.6**

F4d. Accident costs

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Fatal accident	5,195	5,195	58,724	8,041	5,195	**82,351**	2,062	2,141	39,040	5,346	2,223	**50,811**
Serious injury accident	1,931	1,931	36,535	5,147	1,931	**47,477**	1,075	1,101	28,202	3,973	1,127	**35,478**
Minor injury accident	644	644	15,432	1,948	644	**19,312**	503	508	13,831	1,746	513	**17,100**
Total casualty accidents	7,771	7,771	110,692	15,136	7,771	**149,140**	3,639	3,749	81,072	11,065	3,864	**103,389**

F5a. Air pollution

	At initial speed, t/year						At final speed, t/year					
Emissions	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Carbon monoxide CO	180	180	9,820	1,259	179	**11,617**	177	177	8016	1028	177	**9,574**
Hydrocarbons HC	24	24	604	77	24	**753**	20	20	539	69	20	**667**
Oxides of nitrogen NOx	615	610	1,869	240	606	**3,940**	519	519	1568	201	519	**3,327**
Particles PM	102	101	71	9	100	**385**	83	83	57	7	83	**312**
Carbon dioxide CO2	140,809	320,635	316,228	46,516	62,011	**886,199**	128,129	298,571	304,195	43,811	56,905	**831,612**

F5b. Air pollution costs

	At initial speed, k$/year						At final speed, k$/year					
Emissions	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Carbon monoxide CO	0.0	0.0	0.4	0.0	0.0	**0.4**	0.0	0.0	0.3	0.0	0.0	**0.4**
Hydrocarbons HC	0	0	7	1	0	**9**	0	0	6	1	0	**8**
Oxides of nitrogen NOx	15	15	45	6	14	**94**	12	12	37	5	12	**80**
Particles PM	390	385	272	35	381	**1,463**	314	314	218	28	314	**1,188**
Carbon dioxide CO2	5,632	12,825	12,649	1,861	2,480	**35,448**	5,125	11,943	12,168	1,752	2,276	**33,264**
Total	**6,037**	**13,226**	**12,973**	**1,902**	**2,877**	**37,015**	**5,452**	**12,270**	**12,430**	**1,786**	**2,603**	**34,540**

F5c. Noise pollution

No. of residents	**Before policy**	**After policy**	**Change**	
Noise zone 55 to 65 dB			0	#DIV/0!
Noise zone 65 to 70 dB			0	#DIV/0!
Noise zone >70 dB			0	#DIV/0!

F5d. Noise pollution costs

	k$/ year			
	Before policy	**After policy**	**Change**	
Noise zone 55 to 65 dB	0	0	0	#DIV/0!
Noise zone 65 to 70 dB	0	0	0	#DIV/0!
Noise zone >70 dB	0	0	0	#DIV/0!
Total	**0**	**0**	**0**	**#DIV/0!**

G. Non-quantified impacts

Noise pollution

Summary of quantified impacts

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Total monetary impact	136,238	264,367	829,091	132,089	76,126	#######	131,794	255,315	819,933	######	74,606	#######

Application of the MASTER framework

Ver. 01/99

Reduction of cruise speeds to optimum speeds on Category 2 (High Volume National Strategic) roads

H. Net impacts

	Cruise Speed (km/h)	
Trucks (LCV I)	**87.7**	**70**
Cars	**93.9**	**85**

Average speed on link (km/h)	Before	After
Trucks (LCV I)	**85.7**	**69.2**
Cars	**91.9**	**83.8**

H1. Physical impacts

		Before	After	Change	
Total travel time on link, hours/day		52,175	58,004	5,829	11.2 %
Number of Crashes per year		827.7	713.6	-114.1	-13.8%
Emissions, t/year	Carbon monoxide CO	11617	9574	-2043	-17.6 %
	Hydrocarbons HC	753	667	-86.5	-11.5 %
	Oxides of nitrogen NOx	3940	3327	-613	-15.6 %
	Particles PM	384.7	312.2	-72.47	-18.8 %
	Carbon dioxide CO2	886199	831612	-54587	-6.2 %
Residents in area where $L_{Aeq,07-22hrs}$ > 55 d		0	0	0	

Increase/vehicle/100km (mins.) Trucks: **16.7** Cars: **6.3**

Saving p.a. Fatal: **7.3** Serious Inj: **26.0** Other Inj: **80.9**

H2. Monetary impacts

k$/year	**Before**	**After**	**Change**	
Consumer surplus	(N. A.)	(N. A.)		(N. A.)
Vehicle operating costs	730,208	688,927	-41281	-5.7 %
Time costs	521,547	585,799	64252	12.3 %
Crash costs	149,140	103,389	-45,752	-30.7%
Air pollution costs	37,015	34,540	-2,475	-6.7 %
Noise costs (not valued)	0	0	0	
Total	**1,437,910**	**1,412,655**		
Change			**-25,256**	**-1.8 %**

H3. Summary of monetary impacts for each cruise speed

kA$/year km/h	70	75	80	85	90	95	100	105	110	115	120	125	130
Consumer surplus	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)
Vehicle operating costs	670,571	680,733	693,402	708,430	731,016	756,347	784,599	814,394	845,605	878,123	911,851	946,703	982,603
Time costs	680,611	636,425	597,887	564,197	535,195	510,846	490,655	473,003	457,530	443,936	431,968	421,407	412,063
Crash costs	63,277	77,501	94,219	113,738	136,387	162,511	192,479	226,680	265,521	309,433	358,866	414,291	476,202
Air pollution costs	33,826	34,402	35,122	35,981	37,336	38,863	40,574	42,313	44,152	46,085	48,110	50,223	52,420
Noise costs (not valued)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**1,448,285**	**1,429,060**	**1,420,630**	**1,422,345**	**1,439,933**	**1,468,567**	**1,508,307**	**1,556,389**	**1,612,808**	**1,677,578**	**1,750,796**	**1,832,624**	**1,923,288**
of which:													
Heavy vehicles	**461,715**	462,148	465,413	471,406	486,159	503,894	524,040	546,501	571,342	598,592	628,293	660,505	695,301
Cars & light comm. vehs.	986,570	966,913	955,217	**950,939**	953,774	964,673	984,267	1,009,888	1,041,465	1,078,986	1,122,502	1,172,119	1,227,988

H4. Monetary impacts for cars and LCVs at each cruise speed

kA$/year km/h	70	75	80	85	90	95	100	105	110	115	120	125	130
Consumer surplus	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)
Vehicle operating costs	368,317	373,065	379,225	386,673	395,371	405,657	417,985	431,001	444,599	458,685	473,177	487,998	503,082
Time costs	552,725	516,786	485,399	457,913	433,810	413,425	396,636	381,906	368,946	357,514	347,405	338,442	330,475
Crash costs	52,025	63,379	76,672	92,137	110,024	130,599	154,141	180,946	211,326	245,606	284,131	327,258	375,361
Air pollution costs	13,502	13,682	13,921	14,216	14,569	14,992	15,505	16,035	16,594	17,180	17,790	18,420	19,070
Noise costs (not valued)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**986,570**	**966,913**	**955,217**	**950,939**	**953,774**	**964,673**	**984,267**	**1,009,888**	**1,041,465**	**1,078,986**	**1,122,502**	**1,172,119**	**1,227,988**

H5. Monetary impacts for heavy vehicles at each cruise speed

kA$/year km/h	70	75	80	85	90	95	100	105	110	115	120	125	130
Consumer surplus	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)
Vehicle operating costs	302,254	307,668	314,178	321,756	335,645	350,690	366,614	383,393	401,006	419,438	438,674	458,705	479,521
Time costs	127,886	119,639	112,488	106,283	101,385	97,421	94,019	91,096	88,583	86,422	84,563	82,965	81,588
Crash costs	11,252	14,122	17,547	21,602	26,362	31,912	38,338	45,733	54,195	63,827	74,735	87,034	100,841
Air pollution costs	20,324	20,720	21,200	21,765	22,767	23,871	25,068	26,278	27,558	28,905	30,320	31,802	33,350
Noise costs (not valued)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**461,715**	**462,148**	**465,413**	**471,406**	**486,159**	**503,894**	**524,040**	**546,501**	**571,342**	**598,592**	**628,293**	**660,505**	**695,301**

APPENDIX D:
CATEGORY 3 - STRAIGHT NATIONAL & REGIONAL STRATEGIC ROADS

MANAGING SPEEDS OF TRAFFIC ON EUROPEAN ROADS

Application of the MASTER framework (see separate instructions) Ver. 01/99

LINK-LEVEL ANALYSIS OF THE IMPACTS OF A SPEED MANAGEMENT POLICY

Name of applier: Max Cameron
Institution: Monash University Accident Research Centre

1. Outlining

A. Policy test Reduction of cruise speeds to optimum speeds on Category 3 (Straight National & Regional Strategic) roads

A1. Length of link 2824.6 km

A2. Flow characteristics

Traffic attributes	Before policy						After policy					
	HCV1	HCV2	Car	LCV	MCV	**Total/ Average**	HCV1	HCV2	Car	LCV	MCV	**Total/ Average**
Cruise speed, km/h	89.5	88.6	95.8	95.8	87.8	**94.9**	70	70	80	80	70	**78.7**
Average of all speeds on link	86.4	85.3	93.0	92.7	85.3		69.3	69.2	79.2	79.1	69.4	
AADT*	200	200	3,691	473	200	**4,764**	200	200	3,691	473	200	**4,764**
Share of traffic	4%	4%	77%	10%	4%	100%	4%	4%	77%	10%	4%	100%
Business trips, %	85	85	30	55	85	**39**	85	85	30	55	85	**39**
Pers. bus. and commuting. trips,	5	5	10	5	5	**9**	5	5	10	5	5	**9**
Leisure trips, %	10	10	60	40	10	**52**	10	10	60	40	10	**52**

*average annual daily traffic volume, vehicles per day

B. Link/network level analysis

This workbook is best suited for link analysis. However, elastic travel demand can be assumed, for the workbook contains formulas for consumer surplus calculation.

C. Deciding on relevant impacts

- x Vehicle operating costs
- x Travel time
- x Accidents
- x Air pollution
- Noise
- Other

Reduction of cruise speeds to optimum speeds on Category 3 (Straight National & Regional Strategic) roads

2. Measurement of impacts

D. Impact functions

D1. Vehicle operating costs

VOC running cost models from EEM Table A5.11 for speed and grade (adjustment for stops and curves based on EEM Tables 5.24-33)

D2. Travel time

Function: travel time = link length/free speed of traffic flow (flat straight roads only; adjustment for stops and curves based on EEM Tables 5.24-33)

D3a. Accidents

Injury accidents before = n_{IB} Average speed before = v_B

Injury accidents after = n_{IA} Average speed after = v_A

		Exponent	Value	
Fatal accidents	$n_{IA} = (v_A/v_B)F * n_{IB}$	**F**	**4.1**	Rural highway/freeway exponent estimates
Serious injury accidents	$n_{IA} = (v_A/v_B)S * n_{IB}$	**S**	**2.6**	from Cameron and Elvik (2010), Table 8
Other injury accidents	$n_{IA} = (v_A/v_B)O * n_{IB}$	**O**	**1.1**	

Base emissions functions (g/vkt) from EEM table in Appendix A9.3

Source:		Carbon monoxide CO			Oxides of nitrogen NO_x			Particles PO10		
MASTER Working		A	B	C	A	B	C	A	B	C
Paper R1.2.1,	LV	0.00360	-0.545	25.5	0.000246	-0.0287	1.67	#######	-0.00342	0.153
App. D, p. D-6	HV	0.000647	-0.11	7.31	0.002040	-0.275	17.4	0.000382	-0.0455	2.65

D4. Air pollutant emission coefficients

Cruise speed, km/h	89.5	88.6	95.8	95.8	87.8		70	70	80	80	70	
*Emission factors**	**At initial speed, g/km**						**At final speed, g/km**					
	HCV1	HCV2	Car	LCV	MCV	Average	HCV1	HCV2	Car	LCV	MCV	Average
Carbon monoxide CO	2.85	2.85	7.90	7.90	2.84	7.27	2.82	2.82	5.29	5.29	2.82	4.98
Hydrocarbons HC	0.39	0.39	0.47	0.47	0.39	0.46	0.31	0.31	0.36	0.36	0.31	0.35
Oxides of nitrogen NO_x	9.86	9.77	1.49	1.49	9.70	2.53	8.27	8.27	1.02	1.02	8.27	1.93
Particles PM	1.70	1.68	0.06	0.06	1.66	0.262	1.34	1.34	0.04	0.04	1.34	0.202
Carbon dioxide CO_2	2369.8	5334.1	233.4	270.1	1041.6	574.8	2081.2	4790.5	217.3	241.8	930.4	519.9

Emission coefficients for HC not available by vehicle type, only for mix of traffic close to mix outlined here

CO2: EEM function of VOC from row 59 + row 70

CO, Nox, PM: EEM functions with Ding adjustment factors

HC: g/km from 2000 AADT

Flat road 80 kmh	90 kmh
678	739

Adjustment factors for increased emissions due to stops and sharp curves (less than 200m radius) on road

	At initial speed, g/km						**At final speed, g/km**					
	HCV1	HCV2	Car	LCV	MCV		HCV1	HCV2	Car	LCV	MCV	
CO	1.076	1.076	1.249	1.249	1.076		1.014	1.014	1.070	1.070	1.014	
HC	1.064	1.064	1.202	1.202	1.064		1.013	1.013	1.061	1.061	1.013	
NOx	1.080	1.080	1.265	1.265	1.080		1.015	1.015	1.074	1.074	1.015	
PM	1.040	1.040	1.132	1.132	1.040		1.005	1.005	1.035	1.035	1.005	
CO2	Adjusted through VOC adjustments for stops and curves											

D5. Noise pollution

No impact function available; noise pollution assumed small because of negligible human population living in vicinity of rural roads considered

E. Unit prices

	Time cost	VOC	Crash cost		$AUS to $NZ
Base year to 2009 Update factor	1.220	1.000	1.140		1.25

E1. Vehicle operating costs

Source: EEM Table A5.11

		Before policy HCV1	HCV2	Car	LCV	MCV		After policy HCV1	HCV2	Car	LCV	MCV
	a	-75.602	-263.900	24.616	15.852	20.230		-75.602	-263.900	24.616	15.852	20.230
	c	263.07	469.66	43.489	64.641	87.808		263.07	469.66	43.489	64.641	87.808
	e	-101.34	-159.79	-21.157	-30.064	-39.668		-101.34	-159.79	-21.157	-30.064	-39.668
	h	11.615	17.174	2.5663	3.6463	4.8935		11.615	17.174	2.5663	3.6463	4.8935
Zero grade VOC (cents/km)		114.17	177.63	26.35	31.25	57.33		103.58	164.26	24.87	28.63	52.54

		$ per vehicle-km												
		Before policy						After policy						
		HCV1	HCV2	Car	LCV	MCV	Average	HCV1	HCV2	Car	LCV	MCV	Average	GR
Vehicle Operating Costs (VOC)		1.397	3.115	0.255	0.293	0.625	**0.442**	1.285	2.957	0.240	0.266	0.576	**0.415**	
100	b	82.435	2722.4	-44.832	-109.65	-70.181		82.435	2722.4	-44.832	-109.65	-70.181		
####	d	9566.1	15069	-445.63	-118.58	2731.4		9566.1	15069	-445.63	-118.58	2731.4		
100	f	-65.136	-1446.2	38.558	68.678	55.741		-65.136	-1446.2	38.558	68.678	55.741		
####	g	-608.65	-1306	17.595	12.105	-165.84		-608.65	-1306	17.595	12.105	-165.84		
1000	i	-48.388	1796.9	-61.237	-99.936	-147.07		-48.388	1796.9	-61.237	-99.936	-147.07		
1000	j	171.01	488.06	12.523	15.75	58.615		171.01	488.06	12.523	15.75	58.615		
Rolling: Additional VOC for GR4-6		35.74	183.46	-1.22	-2.78	7.35		34.95	180.30	-1.25	-2.81	7.19		5
Mount'ous: Additional VOC for GR7-11		98.88	420.42	-1.25	-3.07	24.51		95.74	410.81	-1.40	-3.27	23.60		9
"Flat": Additional VOC for GR1-3		4.16	39.47	-0.35	-0.89	0.15		4.25	38.72	-0.33	-0.86	0.27		2
Additional VOC for stops/curves		0.085	0.219	0.004	0.007	0.026	**0.018**	0.015	0.037	0.001	0.002	0.005	**0.004**	
(added in row 118, not row 59)		6.06%	7.01%	1.67%	2.47%	4.17%	**4.03%**	1.20%	1.26%	0.57%	0.81%	0.92%	**0.89%**	

Zero grade VOC plus additional VOC for grade (on % vkt applicable)
No update factor applied (because 1 for VOC)

Category 3 roads
% of VKT in terrain

	HV	LV
Rolling	50.95%	51.03%
Mount'ous	5.53%	5.30%
"Flat"	43.52%	43.68%

E2a. Time costs per hour

Value of travel time	$ per hour HCV1	HCV2	Car	LCV	MCV
Business trips, %	55.2	68.6	48.2	49.2	41.8
Pers. bus. and commuting. trips,	12.4	12.4	14.5	14.5	12.4
Leisure trips, %	11.0	11.0	12.9	12.9	11.0
Average	**48.6**	**60.0**	**23.6**	**32.9**	**37.2**

Travel time values at June 2002 from EEM Tables A4.1-2 and vehicle occupancy rates from EEM Table A2.5

E2b. Time costs per kilometre

	$ per vehicle-km											
	Before policy						After policy					
	HCV1	HCV2	Car	LCV	MCV	Average	HCV1	HCV2	Car	LCV	MCV	Average
Time costs	0.563	0.704	0.254	0.355	0.436	**0.3037**	0.702	0.867	0.299	0.416	0.536	**0.3610**

E3. Total user costs
(vehicle operating+ time costs)

	$ per vehicle-km											
	Before policy						After policy					
	HCV1	HCV2	Car	LCV	MCV	Average	HCV1	HCV2	Car	LCV	MCV	Average
Total user costs	1.959	3.819	0.509	0.648	1.061	**0.746**	1.987	3.824	0.539	0.683	1.112	**0.776**

E4. Accident costs

Accident type	**kA$/ accid.**
Fatal accident	4332
Serious injury accident	461.7
Other injury accident	27.4
Personal injury accident (av.)	

Unit costs of reported crashes in 100 km/h speed limit areas from EEM Tables A6.21(e)-(g)

E5a. Air pollution costs

Air pollutants' unit costs	$/t
Carbon monoxide CO	0.038
Hydrocarbons HC	12.0
Oxides of nitrogen NOx	23.9
Particles PM	3804
Carbon dioxide CO2	40.0

Unit cost specified in EEM Section A9.7

Other costs based on unit costs in Table 5.3 in Austroads AGPE04/08 (in NZ$), but only 1% reflecting emissions in rural area

E5b. Noise pollution costs

Unit costs of noise pollution	$/year
Noise zone 55 to 65 dB	
Noise zone 65 to 70 dB	
Noise zone >70 dB	

Treated as zero in rural areas in Table 5.1 of Austroads AGPE04/08

Base VOC with additional for grade on % of vkt applicable on link [calculated at row 59]

Additional VOC for stops and curves [calculates total additional below and converts to $ per veh-km in row 70]

Cruise speed, km/h	89.5	88.6	95.8	95.8	87.8		70	70	80	80	70

F. Calculation of impacts

F1. Vehicle operating costs

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Vehicle operating costs	305,376	687,361	986,988	146,401	134,219	**2,260,345**	268,185	617,308	918,923	131,062	119,895	**2,055,373**

Additional VOC and travel time for stops and slowing for curves

Category 3 roads (Factors for density of stops and curves per 100 km)

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
additional	17,436	45,055	16,170	3,523	5,369	**87,554**	3,184	7,672	5,220	1,055	1,092	**18,223**
% added	6.06%	7.01%	1.67%	2.47%	4.17%	4.03%	1.20%	1.26%	0.57%	0.81%	0.92%	0.89%

F2a. Travel time

	Before policy, vehicle-hours/day						After policy, vehicle-hours/day					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Total travel time on link	6,538	6,621	112,129	14,412	6,619	**146,319**	8,149	8,158	131,696	16,899	8,138	**173,040**

	Before policy, vehicle-hours/day						After policy, vehicle-hours/day					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
additional	227	245	3,299	460	185	**4,416**	79	88	1,373	191	68	**1,799**
@free speed	6,311	6,375	108,830	13,953	6,434	**141,903**	8,070	8,070	130,324	16,708	8,070	**171,241**
% added	3.59%	3.85%	3.03%	3.30%	2.88%	3.11%	0.98%	1.09%	1.05%	1.14%	0.84%	1.05%

F2b. Travel time costs

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Total travel time costs	116,044	145,083	967,440	173,267	89,921	**1,491,755**	144,635	178,756	1,136,265	203,162	110,556	**1,773,374**

Base travel time = length/cruise speed*AADT

Additional travel time calculated above (for total stops and curves on link)

Total travel time [use to calculate average speed on link: row 24 in Outlining]

F3. Consumer surplus

	Input data, before policy						Input data, after policy					
	HCV1	HCV2	Car	LCV	MCV	**Average**	HCV1	HCV2	Car	LCV	MCV	**Average**
Total user costs, $/veh.km	1.959	3.819	0.509	0.648	1.061	**0.746**	1.987	3.824	0.539	0.683	1.112	0.776
Mio veh.kms/year	206	206	3,805	488	206	**4,912**	206	206	3,805	488	206	**4,912**

	Change in consumer surplus					Total
k$/year	5652	1004	111709	17025	10588	**145978**

F4a. Casualty accident rates

	Before policy, crashes/year						After policy, crashes/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Crash rate per million VKT	0.668	0.668	0.668	0.668	0.668	0.668	0.476	0.482	0.527	0.526	0.488	0.522

Category 3 roads adjusted injury crash rate/100M vkt from Summary col. AL

F4b. Casualty accident severity

	Before policy, crashes/year						After policy, crashes/year					
	HCV1	HCV2	Car	LCV	MCV	**Average**	HCV1	HCV2	Car	LCV	MCV	**Average**
Fatal (%)	4.15	4.15	2.06	2.20	4.15	2.34	2.12	2.18	1.25	1.34	2.24	1.37
Serious injury (%)	14.46	14.46	12.05	13.24	14.46	12.47	10.71	10.85	9.55	10.53	10.98	9.80
Minor injury (%)	81.39	81.39	85.89	84.55	81.39	85.19	87.16	86.97	89.20	88.13	86.78	88.83

Open road State Highway

Crash injury severity of adjusted injury crashes

by vehicle type involved (car, LCV, truck)

from email from Fergus Tate 12 June 2012

NOTE: Lower injury severity on Motorways (Cat 1)

F4c. Accidents

	Before policy, crashes/year						After policy, crashes/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Fatal accident	5.7	5.7	52.5	7.2	5.7	**76.8**	2.1	2.2	25.1	3.4	2.3	**35.0**
Serious injury accident	19.9	19.9	306.3	43.1	19.9	**409.1**	10.5	10.8	191.7	27.0	11.0	**251.0**
Minor injury accident	112.1	112.1	2,182.9	275.5	112.1	**2,794.7**	85.5	86.5	1,790.4	226.0	87.4	**2,275.7**
Total casualty accidents	137.7	137.7	2,541.7	325.9	137.7	**3,280.6**	98.1	99.5	2,007.1	256.4	100.7	**2,561.7**

F4d. Accident costs

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Fatal accident	24,732	24,732	227,277	31,121	24,732	**332,593**	9,030	9,412	108,549	14,864	9,769	**151,623**
Serious injury accident	9,194	9,194	141,400	19,921	9,194	**188,903**	4,853	4,982	88,498	12,468	5,101	**115,903**
Minor injury accident	3,067	3,067	59,725	7,538	3,067	**76,463**	2,340	2,366	48,984	6,183	2,390	**62,264**
Total casualty accidents	36,992	36,992	428,402	58,580	36,992	**597,960**	16,223	16,761	246,031	33,514	17,260	**329,789**

F5a. Air pollution

	At initial speed, t/year						At final speed, t/year					
Emissions	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Carbon monoxide CO	588	587	30,076	3,856	586	**35,692**	581	581	20117	2579	581	**24,440**
Hydrocarbons HC	81	80	1,771	227	80	**2,239**	64	64	1368	175	64	**1,737**
Oxides of nitrogen NOx	2,033	2015	5,671	727	2,000	**12,446**	1,705	1705	3875	497	1705	**9,486**
Particles PM	351	347	216	28	343	**1,286**	277	277	143	18	277	**992**
Carbon dioxide CO2	488,601	1,099,778	888,290	131,761	214,750	**2,823,180**	429,096	987,693	827,031	117,956	191,831	**2,553,608**

F5b. Air pollution costs

	At initial speed, k$/year						At final speed, k$/year					
Emissions	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Carbon monoxide CO	0.0	0.0	1.1	0.1	0.0	**1.3**	0.0	0.0	0.8	0.1	0.0	**0.9**
Hydrocarbons HC	1	1	21	3	1	**27**	1	1	16	2	1	**21**
Oxides of nitrogen NOx	49	48	136	17	48	**297**	41	41	93	12	41	**227**
Particles PM	1,336	1,320	823	106	1,305	**4,890**	1,054	1,054	542	70	1,054	**3,774**
Carbon dioxide CO2	19,544	43,991	35,532	5,270	8,590	**112,927**	17,164	39,508	33,081	4,718	7,673	**102,144**
Total	**20,930**	**45,360**	**36,513**	**5,396**	**9,944**	**118,143**	**18,259**	**40,603**	**33,733**	**4,802**	**8,769**	**106,167**

F5c. Noise pollution

No. of residents	**Before policy**	**After policy**	**Change**	
Noise zone 55 to 65 dB			0	#DIV/0!
Noise zone 65 to 70 dB			0	#DIV/0!
Noise zone >70 dB			0	#DIV/0!

F5d. Noise pollution costs

	k$/ year			
	Before policy	**After policy**	**Change**	
Noise zone 55 to 65 dB	0	0	0	#DIV/0!
Noise zone 65 to 70 dB	0	0	0	#DIV/0!
Noise zone >70 dB	0	0	0	#DIV/0!
Total	**0**	**0**	**0**	**#DIV/0!**

G. Non-quantified impacts

Noise pollution

Summary of quantified impacts

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Total monetary impact	479,342	914,797	2,419,343	383,644	271,077	**4,468,202**	447,303	853,429	2,334,952	372,541	256,480	**4,264,704**

MANAGING SPEEDS OF TRAFFIC ON EUROPEAN ROADS

Application of the MASTER framework

Ver. 01/99

Reduction of cruise speeds to optimum speeds on Category 3 (Straight National & Regional Strategic) roads

H. Net impacts

	Cruise Speed (km/h)	
Trucks (LCV I)	**89.5**	**70**
Cars	**95.8**	**80**

Average speed on link (km/h)	Before	After
Trucks (LCV I)	**86.4**	**69.3**
Cars	**93.0**	**79.2**

H1. Physical impacts

		Before	After	Change	
Total travel time on link, hours/day		146,319	173,040	26,720	18.3 %
Number of Crashes per year		3,280.6	2,561.7	-718.9	-21.9%
Emissions, t/year	Carbon monoxide CO	35692	24440	-11252	-31.5 %
	Hydrocarbons HC	2239	1737	-502.1	-22.4 %
	Oxides of nitrogen NOx	12446	9486	-2960	-23.8 %
	Particles PM	1285.5	992.3	-293.29	-22.8 %
	Carbon dioxide CO2	2823180	2553608	-269572	-9.5 %
Residents in area where $L_{Aeq,07\text{-}22hrs}$ > 55 d		0	0	0	

Increase/vehicle/100km (mins.) Trucks: **17.1** Cars: **11.3**

Saving p.a. Fatal: **41.8** Serious Inj: **158.1** Other Inj: **519.0**

H2. Monetary impacts

k$/year	**Before**	**After**	**Change**	
Consumer surplus	(N. A.)	(N. A.)		(N. A.)
Vehicle operating costs	2,260,345	2,055,373	-204972	-9.1 %
Time costs	1,491,755	1,773,374	281619	18.9 %
Crash costs	597,960	329,789	-268,171	-44.8%
Air pollution costs	118,143	106,167	-11,976	-10.1 %
Noise costs (not valued)	0	0	0	
Total	**4,468,202**	**4,264,704**		
Change			**-203,499**	**-4.6 %**

H3. Summary of monetary impacts for each cruise speed

kA$/year km/h	70	75	80	85	90	95	100	105	110	115	120	125	130
Consumer surplus	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)
Vehicle operating costs	2,024,988	2,057,255	2,102,344	2,156,809	2,238,370	2,329,180	2,429,688	2,535,709	2,646,868	2,762,836	2,883,325	3,008,078	3,136,867
Time costs	1,958,502	1,831,881	1,721,951	1,627,585	1,548,568	1,483,444	1,430,647	1,385,283	1,346,290	1,312,774	1,283,972	1,259,225	1,237,961
Crash costs	240,607	294,436	357,674	431,478	517,082	615,793	728,998	858,159	1,004,816	1,170,587	1,357,170	1,566,339	1,799,950
Air pollution costs	104,997	106,889	109,567	112,761	117,814	123,492	129,870	136,231	142,957	150,036	157,456	165,207	173,280
Noise costs (not valued)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**4,329,094**	**4,290,461**	**4,291,536**	**4,328,633**	**4,421,834**	**4,551,909**	**4,719,204**	**4,915,383**	**5,140,932**	**5,396,234**	**5,681,923**	**5,998,849**	**6,348,057**
of which:													
Heavy vehicles	**1,557,211**	1,562,579	1,584,043	1,617,839	1,683,274	1,760,432	1,847,463	1,943,954	2,050,345	2,166,832	2,293,670	2,431,174	2,579,704
Cars & light comm. vehs.	2,771,883	2,727,882	**2,707,493**	2,710,794	2,738,560	2,791,478	2,871,741	2,971,429	3,090,587	3,229,403	3,388,252	3,567,675	3,768,353

H4. Monetary impacts for cars and LCVs at each cruise speed

kA$/year km/h	70	75	80	85	90	95	100	105	110	115	120	125	130
Consumer surplus	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)
Vehicle operating costs	1,019,600	1,032,834	1,049,986	1,071,197	1,097,118	1,127,677	1,164,275	1,202,804	1,242,952	1,284,439	1,327,015	1,370,454	1,414,549
Time costs	1,524,555	1,425,705	1,339,427	1,264,822	1,201,059	1,147,965	1,105,266	1,068,353	1,036,406	1,008,735	984,754	963,955	945,899
Crash costs	190,363	231,475	279,545	335,411	399,965	474,152	558,974	655,484	764,796	888,075	1,026,545	1,181,486	1,354,233
Air pollution costs	37,365	37,868	38,535	39,363	40,418	41,682	43,226	44,788	46,434	48,154	49,939	51,781	53,672
Noise costs (not valued)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**2,771,883**	**2,727,882**	**2,707,493**	**2,710,794**	**2,738,560**	**2,791,478**	**2,871,741**	**2,971,429**	**3,090,587**	**3,229,403**	**3,388,252**	**3,567,675**	**3,768,353**

H5. Monetary impacts for heavy vehicles at each cruise speed

kA$/year km/h	70	75	80	85	90	95	100	105	110	115	120	125	130
Consumer surplus	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)
Vehicle operating costs	1,005,388	1,024,422	1,052,358	1,085,612	1,141,252	1,201,503	1,265,413	1,332,905	1,403,917	1,478,398	1,556,310	1,637,624	1,722,318
Time costs	433,947	406,176	382,525	362,763	347,510	335,478	325,382	316,931	309,885	304,039	299,218	295,270	292,062
Crash costs	50,244	62,961	78,129	96,067	117,117	141,641	170,025	202,675	240,020	282,512	330,625	384,853	445,716
Air pollution costs	67,632	69,021	71,031	73,398	77,396	81,810	86,644	91,443	96,524	101,883	107,517	113,426	119,607
Noise costs (not valued)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**1,557,211**	**1,562,579**	**1,584,043**	**1,617,839**	**1,683,274**	**1,760,432**	**1,847,463**	**1,943,954**	**2,050,345**	**2,166,832**	**2,293,670**	**2,431,174**	**2,579,704**

APPENDIX E:
CATEGORY 4 - WINDING NATIONAL & REGIONAL STRATEGIC ROADS

MANAGING SPEEDS OF TRAFFIC ON EUROPEAN ROADS

Application of the MASTER framework (see separate instructions) Ver. 01/99

LINK-LEVEL ANALYSIS OF THE IMPACTS OF A SPEED MANAGEMENT POLICY

Name of applier: Max Cameron
Institution: Monash University Accident Research Centre

1. Outlining

A. Policy test Reduction of cruise speeds to optimum speeds on Category 4 (Winding National & Regional Strategic) roads

A1. Length of link 342.6 km

A2. Flow characteristics

Traffic attributes	Before policy						After policy					
	HCV1	HCV2	Car	LCV	MCV	**Total/ Average**	HCV1	HCV2	Car	LCV	MCV	**Total/ Average**
Cruise speed, km/h	78.4	77.8	83.6	83.6	77.2	**82.8**	70	70	75	75	70	**74.3**
Average of all speeds on link	75.6	74.8	79.6	79.2	74.9		68.4	68.2	72.6	72.4	68.6	
AADT*	197	197	3,446	442	197	**4,478**	197	197	3,446	442	197	**4,478**
Share of traffic	4%	4%	77%	10%	4%	100%	4%	4%	77%	10%	4%	100%
Business trips, %	85	85	30	55	85	**40**	85	85	30	55	85	**40**
Pers. bus. and commuting. trips,	5	5	10	5	5	**9**	5	5	10	5	5	**9**
Leisure trips, %	10	10	60	40	10	**51**	10	10	60	40	10	**51**

*average annual daily traffic volume, vehicles per day

B. Link/network level analysis

This workbook is best suited for link analysis. However, elastic travel demand can be assumed, for the workbook contains formulas for consumer surplus calculation.

C. Deciding on relevant impacts

- [x] Vehicle operating costs
- [x] Travel time
- [x] Accidents
- [x] Air pollution
- [ ] Noise
- [ ] Other

Reduction of cruise speeds to optimum speeds on Category 4 (Winding National & Regional Strategic) roads

2. Measurement of impacts

D. Impact functions

D1. Vehicle operating costs

VOC running cost models from EEM Table A5.11 for speed and grade (adjustment for stops and curves based on EEM Tables 5.24-33)

D2. Travel time

Function: travel time = link length/free speed of traffic flow (flat straight roads only; adjustment for stops and curves based on EEM Tables 5.24-33)

D3a. Accidents

Injury accidents before = n_{IB} Average speed before = v_B

Injury accidents after = n_{IA} Average speed after = v_A

		Exponent	Value	
Fatal accidents	$n_{IA} = (v_A/v_B)F * n_{IB}$	**F**	**4.1**	Rural highway/freeway exponent estimates
Serious injury accidents	$n_{IA} = (v_A/v_B)S * n_{IB}$	**S**	**2.6**	from Cameron and Elvik (2010), Table 8
Other injury accidents	$n_{IA} = (v_A/v_B)O * n_{IB}$	**O**	**1.1**	

Base emissions functions (g/vkt) from EEM table in Appendix A9.3

Source:		Carbon monoxide CO			Oxides of nitrogen NO_x			Particles PO10		
MASTER Working		A	B	C	A	B	C	A	B	C
Paper R1.2.1,	LV	0.00360	-0.545	25.5	0.000246	-0.0287	1.67	#######	-0.00342	0.153
App. D, p. D-6	HV	0.000647	-0.11	7.31	0.002040	-0.275	17.4	0.000382	-0.0455	2.65

D4. Air pollutant emission coefficients

Cruise speed, km/h	78.4	77.8	83.6	83.6	77.2		70	70	75	75	70		HC: g/km from 2000 AADT	
*Emission factors**	**At initial speed, g/km**						**At final speed, g/km**						Flat road	
	HCV1	HCV2	Car	LCV	MCV	Average	HCV1	HCV2	Car	LCV	MCV	Average	80 kmh	90 kmh
Carbon monoxide CO	2.87	2.88	5.78	5.78	2.88	5.40	2.84	2.84	5.26	5.26	2.84	4.94		
Hydrocarbons HC	0.36	0.35	0.39	0.39	0.35	0.39	0.31	0.31	0.35	0.35	0.31	0.34	678	739
Oxides of nitrogen NO_x	9.07	9.04	1.13	1.13	9.01	2.17	8.34	8.34	0.98	0.98	8.34	1.95		
Particles PM	1.49	1.48	0.04	0.04	1.47	0.230	1.35	1.35	0.04	0.04	1.35	0.209		
Carbon dioxide CO_2	2594.3	6612.7	221.5	247.1	1073.8	646.3	2477.0	6394.5	213.7	232.9	1031.6	622.3		

Emission coefficients for HC not available by vehicle type, only for mix of traffic close to mix outlined here

CO2: EEM function of VOC from row 59 + row 70

CO, Nox, PM: EEM functions with Ding adjustment factors

Adjustment factors for increased emissions due to stops and sharp curves (less than 200m radius) on road

	At initial speed, g/km						**At final speed, g/km**					
	HCV1	HCV2	Car	LCV	MCV		HCV1	HCV2	Car	LCV	MCV	
CO	1.078	1.078	1.134	1.134	1.078		1.022	1.022	1.078	1.078	1.022	
HC	1.067	1.067	1.115	1.115	1.067		1.019	1.019	1.067	1.067	1.019	
NOx	1.082	1.082	1.141	1.141	1.082		1.023	1.023	1.082	1.082	1.023	
PM	1.038	1.038	1.067	1.067	1.038		1.008	1.008	1.038	1.038	1.008	
CO2	Adjusted through VOC adjustments for stops and curves											

D5. Noise pollution

No impact function available; noise pollution assumed small because of negligible human population living in vicinity of rural roads considered

E. Unit prices

	Time cost	VOC	Crash cost	$AUS to $NZ
Base year to 2009 Update factor	1.220	1.000	1.140	1.25

E1. Vehicle operating costs

		Before policy HCV1	HCV2	Car	LCV	MCV	Average	After policy HCV1	HCV2	Car	LCV	MCV	Average	GR
	a	-75.602	-263.900	24.616	15.852	20.230		-75.602	-263.900	24.616	15.852	20.230		
	c	263.07	469.66	43.489	64.641	87.808		263.07	469.66	43.489	64.641	87.808		
	e	-101.34	-159.79	-21.157	-30.064	-39.668		-101.34	-159.79	-21.157	-30.064	-39.668		
	h	11.615	17.174	2.5663	3.6463	4.8935		11.615	17.174	2.5663	3.6463	4.8935		
Zero grade VOC (cents/km)		107.70	169.36	25.15	29.16	54.30		103.58	164.26	24.54	27.98	52.54		
		$ per vehicle-km												
		Before policy						**After policy**						
		HCV1	HCV2	Car	LCV	MCV	**Average**	HCV1	HCV2	Car	LCV	MCV	**Average**	
Vehicle Operating Costs (VOC)		1.554	3.966	0.239	0.263	0.650	**0.481**	1.506	3.896	0.233	0.251	0.630	**0.469**	
100	b	82.435	2722.4	-44.832	-109.65	-70.181		82.435	2722.4	-44.832	-109.65	-70.181		
####	d	9566.1	15069	-445.63	-118.58	2731.4		9566.1	15069	-445.63	-118.58	2731.4		
100	f	-65.136	-1446.2	38.558	68.678	55.741		-65.136	-1446.2	38.558	68.678	55.741		
####	g	-608.65	-1306	17.595	12.105	-165.84		-608.65	-1306	17.595	12.105	-165.84		
1000	i	-48.388	1796.9	-61.237	-99.936	-147.07		-48.388	1796.9	-61.237	-99.936	-147.07		
1000	j	171.01	488.06	12.523	15.75	58.615		171.01	488.06	12.523	15.75	58.615		GR
Rolling: Additional VOC for GR4-6		35.32	181.69	-1.24	-2.80	7.26		34.95	180.30	-1.26	-2.83	7.19		5
Mount'ous: Additional VOC for GR7-11		97.19	415.10	-1.37	-3.22	24.00		95.74	410.81	-1.46	-3.34	23.60		9
"Flat": Additional VOC for GR1-3		4.21	39.03	-0.33	-0.87	0.22		4.25	38.72	-0.32	-0.86	0.27		2
Additional VOC for stops/curves		0.068	0.167	0.007	0.011	0.022	**0.018**	0.042	0.101	0.005	0.008	0.014	**0.011**	
(added in row 118, not row 59)		4.37%	4.20%	2.90%	4.25%	3.33%	**3.68%**	2.77%	2.59%	2.05%	3.06%	2.26%	**2.42%**	

Source: EEM Table A5.11

Zero grade VOC plus additional VOC for grade (on % vkt applicable)
No update factor applied (because 1 for VOC)

Category 4 roads
% of VKT in terrain

HV	LV
74.35%	73.21%
21.85%	23.10%
3.80%	3.69%

E2a. Time costs per hour

Value of travel time	**$ per hour** HCV1	HCV2	Car	LCV	MCV
Business trips, %	55.2	68.6	48.2	49.2	41.8
Pers. bus. and commuting. trips,	12.4	12.4	14.5	14.5	12.4
Leisure trips, %	11.0	11.0	12.9	12.9	11.0
Average	**48.6**	**60.0**	**23.6**	**32.9**	**37.2**

Travel time values at June 2002 from EEM Tables A4.1-2 and vehicle occupancy rates from EEM Table A2.5

E2b. Time costs per kilometre

	$ per vehicle-km											
	Before policy						**After policy**					
	HCV1	HCV2	Car	LCV	MCV	**Average**	HCV1	HCV2	Car	LCV	MCV	**Average**
Time costs	0.643	0.803	0.297	0.416	0.497	**0.3550**	0.711	0.880	0.326	0.455	0.543	**0.3892**

E3. Total user costs
(vehicle operating+ time costs)

	$ per vehicle-km											
	Before policy						**After policy**					
	HCV1	HCV2	Car	LCV	MCV	**Average**	HCV1	HCV2	Car	LCV	MCV	**Average**
Total user costs	2.197	4.769	0.536	0.679	1.146	**0.836**	2.218	4.776	0.558	0.706	1.173	**0.858**

E4. Accident costs

Accident type	**kA$/ accid.**
Fatal accident	4332
Serious injury accident	461.7
Other injury accident	27.4
Personal injury accident (av.)	

Unit costs of reported crashes in 100 km/h speed limit areas from EEM Tables A6.21(e)-(g)

E5a. Air pollution costs

Air pollutants' unit costs	$/t
Carbon monoxide CO	0.038
Hydrocarbons HC	12.0
Oxides of nitrogen NOx	23.9
Particles PM	3804
Carbon dioxide CO2	40.0

Unit cost specified in EEM Section A9.7

Other costs based on unit costs in Table 5.3 in Austroads AGPE04/08 (in NZ$), but only 1% reflecting emissions in rural area

E5b. Noise pollution costs

Unit costs of noise pollution	$/year
Noise zone 55 to 65 dB	
Noise zone 65 to 70 dB	
Noise zone >70 dB	

Treated as zero in rural areas in Table 5.1 of Austroads AGPE04/08

Base VOC with additional for grade on % of vkt applicable on link [calculated at row 59]

Additional VOC for stops and curves [calculates total additional below and converts to $ per veh-km in row 70]

Cruise speed, km/h	78.4	77.8	83.6	83.6	77.2	70	70	75	75	70

F. Calculation of impacts

F1. Vehicle operating costs

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Vehicle operating costs	39,865	101,615	106,025	15,165	16,501	**279,172**	38,064	98,262	102,300	14,297	15,852	**268,775**

Additional VOC and travel time for stops and slowing for curves

Category 4 roads (Factors for density of stops and curves per 100 km)

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
additional	1,669	4,095	2,990	618	532	**9,905**	1,025	2,485	2,058	425	350	**6,342**
% added	4.37%	4.20%	2.90%	4.25%	3.33%	3.68%	2.77%	2.59%	2.05%	3.06%	2.26%	2.42%

F2a. Travel time

	Before policy, vehicle-hours/day						After policy, vehicle-hours/day					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Total travel time on link	891	901	14,837	1,910	899	**19,438**	985	988	16,262	2,090	982	**21,307**

	Before policy, vehicle-hours/day						After policy, vehicle-hours/day					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
additional	32	35	716	100	26	**909**	23	25	522	72	20	**662**
@free speed	859	866	14,121	1,810	873	**18,529**	962	962	15,740	2,018	962	**20,645**
% added	3.72%	4.03%	5.07%	5.51%	3.03%	4.91%	2.37%	2.63%	3.32%	3.59%	2.04%	3.21%

F2b. Travel time costs

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Total travel time costs	15,818	19,737	128,014	22,963	12,213	**198,745**	17,484	21,641	140,309	25,130	13,340	**217,903**

Base travel time = length/cruise speed*AADT

Additional travel time calculated above (for total stops and curves on link)

Total travel time [use to calculate average speed on link: row 24 in Outlining]

F3. Consumer surplus

	Input data, before policy						Input data, after policy					
	HCV1	HCV2	Car	LCV	MCV	**Average**	HCV1	HCV2	Car	LCV	MCV	**Average**
Total user costs, $/veh.km	2.197	4.769	0.536	0.679	1.146	**0.836**	2.218	4.776	0.558	0.706	1.173	0.858
Mio veh.kms/year	25	25	431	55	25	**560**	25	25	431	55	25	**560**

	Change in consumer surplus					**Total**
k$/year	509	161	9502	1492	659	**12324**

F4a. Casualty accident rates

	Before policy, crashes/year						After policy, crashes/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Crash rate per million VKT	0.589	0.589	0.589	0.589	0.589	0.589	0.502	0.507	0.510	0.509	0.513	0.509

Category 4 roads adjusted injury crash rate/100M vkt from Summary col. AL

F4b. Casualty accident severity

	Before policy, crashes/year						After policy, crashes/year					
	HCV1	HCV2	Car	LCV	MCV	**Average**	HCV1	HCV2	Car	LCV	MCV	**Average**
Fatal (%)	4.15	4.15	2.06	2.20	4.15	2.35	3.06	3.12	1.53	1.63	3.19	1.75
Serious injury (%)	14.46	14.46	12.05	13.24	14.46	12.48	12.64	12.76	10.49	11.55	12.88	10.89
Minor injury (%)	81.39	81.39	85.89	84.55	81.39	85.16	84.31	84.12	87.98	86.81	83.94	87.36

Open road State Highway

Crash injury severity of adjusted injury crashes

by vehicle type involved (car, LCV, truck)

from email from Fergus Tate 12 June 2012

NOTE: Lower injury severity on Motorways (Cat 1)

F4c. Accidents

	Before policy, crashes/year						After policy, crashes/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Fatal accident	0.6	0.6	5.2	0.7	0.6	**7.8**	0.4	0.4	3.4	0.5	0.4	**5.0**
Serious injury accident	2.1	2.1	30.6	4.3	2.1	**41.1**	1.6	1.6	23.0	3.2	1.6	**31.1**
Minor injury accident	11.8	11.8	217.9	27.5	11.8	**280.7**	10.4	10.5	193.3	24.4	10.6	**249.2**
Total casualty accidents	14.5	14.5	253.7	32.5	14.5	**329.6**	12.3	12.5	219.7	28.1	12.6	**285.3**

F4d. Accident costs

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Fatal accident	2,600	2,600	22,682	3,106	2,600	**33,587**	1,633	1,686	14,534	1,990	1,740	**21,583**
Serious injury accident	966	966	14,112	1,988	966	**18,999**	720	734	10,641	1,499	749	**14,344**
Minor injury accident	322	322	5,961	752	322	**7,680**	285	287	5,290	668	289	**6,818**
Total casualty accidents	3,888	3,888	42,754	5,846	3,888	**60,265**	2,638	2,707	30,465	4,157	2,779	**42,746**

F5a. Air pollution

	At initial speed, t/year						At final speed, t/year					
Emissions	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Carbon monoxide CO	71	71	2,491	319	71	**3,023**	70	70	2265	290	70	**2,765**
Hydrocarbons HC	9	9	168	22	9	**216**	8	8	149	19	8	**191**
Oxides of nitrogen NOx	223	222	487	62	222	**1,216**	205	205	420	54	205	**1,089**
Particles PM	37	36	18	2	36	**129**	33	33	15	2	33	**117**
Carbon dioxide CO2	63,785	162,584	95,423	13,649	26,402	**361,842**	60,902	157,220	92,070	12,867	25,363	**348,422**

F5b. Air pollution costs

	At initial speed, k$/year						At final speed, k$/year					
Emissions	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Carbon monoxide CO	0.0	0.0	0.1	0.0	0.0	**0.1**	0.0	0.0	0.1	0.0	0.0	**0.1**
Hydrocarbons HC	0	0	2	0	0	**3**	0	0	2	0	0	**2**
Oxides of nitrogen NOx	5	5	12	1	5	**29**	5	5	10	1	5	**26**
Particles PM	139	138	67	9	137	**490**	126	126	58	7	126	**444**
Carbon dioxide CO2	2,551	6,503	3,817	546	1,056	**14,474**	2,436	6,289	3,683	515	1,015	**13,937**
Total	**2,696**	**6,647**	**3,898**	**556**	**1,199**	**14,995**	**2,567**	**6,420**	**3,753**	**524**	**1,146**	**14,409**

F5c. Noise pollution

No. of residents	**Before policy**	**After policy**	**Change**	
Noise zone 55 to 65 dB			0	#DIV/0!
Noise zone 65 to 70 dB			0	#DIV/0!
Noise zone >70 dB			0	#DIV/0!

F5d. Noise pollution costs

	k$/ year			
	Before policy	**After policy**	**Change**	
Noise zone 55 to 65 dB	0	0	0	#DIV/0!
Noise zone 65 to 70 dB	0	0	0	#DIV/0!
Noise zone >70 dB	0	0	0	#DIV/0!
Total	**0**	**0**	**0**	**#DIV/0!**

G. Non-quantified impacts

Noise pollution

Summary of quantified impacts

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Total monetary impact	62,267	131,887	280,691	44,531	33,801	**553,178**	60,753	129,030	276,827	44,108	33,115	**543,833**

Application of the MASTER framework

Ver. 01/99

Reduction of cruise speeds to optimum speeds on Category 4 (Winding National & Regional Strategic) roads

H. Net impacts

	Cruise Speed (km/h)	
Trucks (LCV I)	**78.4**	**70**
Cars	**83.6**	**75**

Average speed on link (km/h)	Before	After
Trucks (LCV I)	**75.6**	**68.4**
Cars	**79.6**	**72.6**

H1. Physical impacts

		Before	After	Change	
Total travel time on link, hours/day		19,438	21,307	1,869	9.6 %
Number of Crashes per year		329.6	285.3	-44.3	-13.5%
Emissions, t/year	Carbon monoxide CO	3023	2765	-258	-8.5 %
	Hydrocarbons HC	216	191	-24.7	-11.5 %
	Oxides of nitrogen NOx	1216	1089	-127	-10.4 %
	Particles PM	128.8	116.7	-12.03	-9.3 %
	Carbon dioxide CO2	361842	348422	-13421	-3.7 %
Residents in area where $L_{Aeq,07-22hrs}$ > 55 d		0	0	0	

Increase/vehicle/100km (mins.) Trucks: **8.4** Cars: **7.2**

Saving p.a. Fatal: **2.8** Serious Inj: **10.1** Other Inj: **31.5**

H2. Monetary impacts

k$/year	**Before**	**After**	**Change**	
Consumer surplus	(N. A.)	(N. A.)		(N. A.)
Vehicle operating costs	279,172	268,775	-10397	-3.7 %
Time costs	198,745	217,903	19159	9.6 %
Crash costs	60,265	42,746	-17,520	-29.1%
Air pollution costs	14,995	14,409	-586	-3.9 %
Noise costs (not valued)	0	0	0	
Total	**553,178**	**543,833**		
Change			**-9,344**	**-1.7 %**

H3. Summary of monetary impacts for each cruise speed

kA$/year km/h	70	75	80	85	90	95	100	105	110	115	120	125	130
Consumer surplus	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)
Vehicle operating costs	266,712	272,005	279,210	287,722	299,472	312,376	326,488	341,327	356,846	373,004	389,766	407,098	424,970
Time costs	228,178	214,786	203,311	193,755	186,105	180,030	175,353	171,510	168,375	165,842	163,817	162,222	160,985
Crash costs	36,245	44,900	55,146	67,183	81,226	97,502	116,254	137,736	162,217	189,979	221,318	256,545	295,984
Air pollution costs	14,331	14,643	15,074	15,570	16,308	17,132	18,056	18,948	19,890	20,880	21,917	22,999	24,125
Noise costs (not valued)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**545,466**	**546,333**	**552,741**	**564,230**	**583,110**	**607,040**	**636,151**	**669,521**	**707,328**	**749,705**	**796,818**	**848,864**	**906,064**
of which:													
Heavy vehicles	**222,898**	225,398	230,398	237,211	247,836	260,119	273,888	289,080	305,804	324,111	344,060	365,719	389,162
Cars & light comm. vehs.	322,568	**320,935**	322,343	327,019	335,274	346,921	362,263	380,441	401,523	425,593	452,758	483,144	516,902

H4. Monetary impacts for cars and LCVs at each cruise speed

kA$/year km/h	70	75	80	85	90	95	100	105	110	115	120	125	130
Consumer surplus	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)
Vehicle operating costs	114,535	116,597	119,117	122,166	125,909	130,189	135,164	140,358	145,733	151,250	156,878	162,586	168,345
Time costs	175,713	165,439	156,568	149,109	143,041	138,179	134,487	131,438	128,934	126,894	125,247	123,932	122,895
Crash costs	28,122	34,622	42,284	51,252	61,679	73,729	87,574	103,397	121,389	141,754	164,701	190,454	219,243
Air pollution costs	4,198	4,277	4,375	4,492	4,645	4,824	5,038	5,248	5,468	5,696	5,931	6,173	6,420
Noise costs (not valued)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**322,568**	**320,935**	**322,343**	**327,019**	**335,274**	**346,921**	**362,263**	**380,441**	**401,523**	**425,593**	**452,758**	**483,144**	**516,902**

H5. Monetary impacts for heavy vehicles at each cruise speed

kA$/year km/h	70	75	80	85	90	95	100	105	110	115	120	125	130
Consumer surplus	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)
Vehicle operating costs	152,178	155,408	160,094	165,556	173,563	182,187	191,325	200,969	211,113	221,754	232,888	244,512	256,626
Time costs	52,465	49,347	46,743	44,646	43,063	41,851	40,866	40,072	39,441	38,948	38,570	38,290	38,090
Crash costs	8,123	10,278	12,861	15,931	19,546	23,773	28,680	34,339	40,827	48,225	56,617	66,091	76,742
Air pollution costs	10,133	10,366	10,699	11,078	11,663	12,308	13,018	13,700	14,423	15,185	15,986	16,826	17,705
Noise costs (not valued)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**222,898**	**225,398**	**230,398**	**237,211**	**247,836**	**260,119**	**273,888**	**289,080**	**305,804**	**324,111**	**344,060**	**365,719**	**389,162**

APPENDIX F:
CATEGORY 5 - STRAIGHT REGIONAL CONNECTOR & DISTRIBUTOR ROADS

MANAGING SPEEDS OF TRAFFIC ON EUROPEAN ROADS

Application of the MASTER framework (see separate instructions) Ver. 01/99

LINK-LEVEL ANALYSIS OF THE IMPACTS OF A SPEED MANAGEMENT POLICY

Name of applier: Max Cameron
Institution: Monash University Accident Research Centre

1. Outlining

A. Policy test Reduction of cruise speeds to optimum speeds on Category 5 (Straight Regional Other) roads

A1. Length of link 4920.3 km

A2. Flow characteristics

Traffic attributes	Before policy						After policy					
	HCV1	HCV2	Car	LCV	MCV	**Total/ Average**	HCV1	HCV2	Car	LCV	MCV	**Total/ Average**
Cruise speed, km/h	89.4	88.5	95.7	95.7	87.7	**94.8**	70	70	80	80	70	**78.8**
Average of all speeds on link	84.0	82.8	90.2	89.7	83.4		68.6	68.5	78.1	77.9	68.8	
AADT*	83	62	1,459	162	83	**1,850**	83	62	1,459	162	83	**1,850**
Share of traffic	4%	3%	79%	9%	4%	100%	4%	3%	79%	9%	4%	100%
Business trips, %	85	85	30	55	85	**39**	85	85	30	55	85	**39**
Pers. bus. and commuting. trips,	5	5	10	5	5	**9**	5	5	10	5	5	**9**
Leisure trips, %	10	10	60	40	10	**52**	10	10	60	40	10	**52**

*average annual daily traffic volume, vehicles per day

B. Link/network level analysis

This workbook is best suited for link analysis. However, elastic travel demand can be assumed, for the workbook contains formulas for consumer surplus calculation.

C. Deciding on relevant impacts

- [x] Vehicle operating costs
- [x] Travel time
- [x] Accidents
- [x] Air pollution
- [ ] Noise
- [ ] Other

Reduction of cruise speeds to optimum speeds on Category 5 (Straight Regional Other) roads

2. Measurement of impacts

D. Impact functions

D1. Vehicle operating costs

VOC running cost models from EEM Table A5.11 for speed and grade (adjustment for stops and curves based on EEM Tables 5.24-33)

D2. Travel time

Function: travel time = link length/free speed of traffic flow (flat straight roads only; adjustment for stops and curves based on EEM Tables 5.24-33)

D3a. Accidents

Injury accidents before = n_{IB} Average speed before = v_B

Injury accidents after = n_{IA} Average speed after = v_A

		Exponent	Value	
Fatal accidents	$n_{IA} = (v_A/v_B)F * n_{IB}$	F	**4.1**	Rural highway/freeway exponent estimates
Serious injury accidents	$n_{IA} = (v_A/v_B)S * n_{IB}$	S	**2.6**	from Cameron and Elvik (2010), Table 8
Other injury accidents	$n_{IA} = (v_A/v_B)O * n_{IB}$	O	**1.1**	

Base emissions functions (g/vkt) from EEM table in Appendix A9.3

Source:		Carbon monoxide CO			Oxides of nitrogen NO_x			Particles PO10		
MASTER Working		A	B	C	A	B	C	A	B	C
Paper R1.2.1,	LV	0.00360	-0.545	25.5	0.000246	-0.0287	1.67	#######	-0.00342	0.153
App. D, p. D-6	HV	0.000647	-0.11	7.31	0.002040	-0.275	17.4	0.000382	-0.0455	2.65

D4. Air pollutant emission coefficients

Cruise speed, km/h	89.4	88.5	95.7	95.7	87.7		70	70	80	80	70		HC: g/km from 2000 AADT	
*Emission factors**	At initial speed, g/km						At final speed, g/km						Flat road	
	HCV1	HCV2	Car	LCV	MCV	Average	HCV1	HCV2	Car	LCV	MCV	Average	80 kmh	90 kmh
Carbon monoxide CO	2.99	2.99	8.97	8.97	2.98	8.23	2.85	2.85	5.54	5.54	2.85	5.20		
Hydrocarbons HC	0.41	0.40	0.52	0.52	0.40	0.50	0.32	0.32	0.37	0.37	0.32	0.37	678	739
Oxides of nitrogen NO_x	10.36	10.27	1.71	1.71	10.19	2.76	8.36	8.36	1.07	1.07	8.36	1.97		
Particles PM	1.75	1.72	0.06	0.06	1.71	0.267	1.35	1.35	0.04	0.04	1.35	0.200		
Carbon dioxide CO_2	2485.0	5675.5	236.8	275.3	1075.4	562.1	2133.9	4971.0	218.8	244.0	945.7	499.9		

Emission coefficients for HC not available by vehicle type, only for mix of traffic close to mix outlined here

CO2: EEM function of VOC from row 59 + row 70

CO, Nox, PM: EEM functions with Ding adjustment factors

Adjustment factors for increased emissions due to stops and sharp curves (less than 200m radius) on road

	At initial speed, g/km						At final speed, g/km					
	HCV1	HCV2	Car	LCV	MCV		HCV1	HCV2	Car	LCV	MCV	
CO	1.130	1.130	1.421	1.421	1.130		1.025	1.025	1.121	1.121	1.025	
HC	1.109	1.109	1.337	1.337	1.109		1.022	1.022	1.104	1.104	1.022	
NOx	1.136	1.136	1.449	1.449	1.136		1.026	1.026	1.127	1.127	1.026	
PM	1.068	1.068	1.218	1.218	1.068		1.009	1.009	1.060	1.060	1.009	
CO2	Adjusted through VOC adjustments for stops and curves											

D5. Noise pollution

No impact function available; noise pollution assumed small because of negligible human population living in vicinity of rural roads considered

E. Unit prices

Base year to 2009	Time cost	VOC	Crash cost		$AUS to $NZ
Update factor	1.220	1.000	1.140		1.25

E1. Vehicle operating costs

Source: EEM Table A5.11

			Before policy: HCV1	HCV2	Car	LCV	MCV	Average	After policy: HCV1	HCV2	Car	LCV	MCV	Average
		a	-75.602	-263.900	24.616	15.852	20.230		-75.602	-263.900	24.616	15.852	20.230	
		c	263.07	469.66	43.489	64.641	87.808		263.07	469.66	43.489	64.641	87.808	
		e	-101.34	-159.79	-21.157	-30.064	-39.668		-101.34	-159.79	-21.157	-30.064	-39.668	
		h	11.615	17.174	2.5663	3.6463	4.8935		11.615	17.174	2.5663	3.6463	4.8935	
	Zero grade VOC (cents/km)		114.11	177.55	26.34	31.24	57.29		103.58	164.26	24.87	28.63	52.54	
	$ per vehicle-km													
	Vehicle Operating Costs (VOC)		1.414	3.191	0.255	0.292	0.629	**0.426**	1.303	3.032	0.240	0.266	0.580	**0.399**
100		b	82.435	2722.4	-44.832	-109.65	-70.181		82.435	2722.4	-44.832	-109.65	-70.181	
####		d	9566.1	15069	-445.63	-118.58	2731.4		9566.1	15069	-445.63	-118.58	2731.4	
100		f	-65.136	-1446.2	38.558	68.678	55.741		-65.136	-1446.2	38.558	68.678	55.741	
####		g	-608.65	-1306	17.595	12.105	-165.84		-608.65	-1306	17.595	12.105	-165.84	
1000		i	-48.388	1796.9	-61.237	-99.936	-147.07		-48.388	1796.9	-61.237	-99.936	-147.07	
1000		j	171.01	488.06	12.523	15.75	58.615		171.01	488.06	12.523	15.75	58.615	
Rolling:	Additional VOC for GR4-6		35.73	183.45	-1.22	-2.78	7.35		34.95	180.30	-1.25	-2.81	7.19	
Mount'ous:	Additional VOC for GR7-11		98.87	420.37	-1.25	-3.07	24.51		95.74	410.81	-1.40	-3.27	23.60	
"Flat":	Additional VOC for GR1-3		4.16	39.46	-0.35	-0.89	0.16		4.25	38.72	-0.33	-0.86	0.27	
	Additional VOC for stops/curves		0.139	0.356	0.008	0.014	0.043	**0.028**	0.031	0.075	0.003	0.005	0.011	**0.007**
	(added in row 118, not row 59)		9.84%	11.15%	3.26%	4.70%	6.86%	**6.56%**	2.38%	2.46%	1.35%	1.93%	1.83%	**1.85%**

Zero grade VOC plus additional VOC for grade (on % vkt applicable)
No update factor applied (because 1 for VOC)

Category 5 roads
% of VKT in terrain

GR	HV	LV
5	53.62%	51.51%
9	6.54%	7.15%
2	39.84%	41.33%

E2a. Time costs per hour

Value of travel time	$ per hour: HCV1	HCV2	Car	LCV	MCV
Business trips, %	55.2	68.6	48.2	49.2	41.8
Pers. bus. and commuting. trips,	12.4	12.4	14.5	14.5	12.4
Leisure trips, %	11.0	11.0	12.9	12.9	11.0
Average	**48.6**	**60.0**	**23.6**	**32.9**	**37.2**

Travel time values at June 2002 from EEM Tables A4.1-2 and vehicle occupancy rates from EEM Table A2.5

E2b. Time costs per kilometre

$ per vehicle-km	Before policy: HCV1	HCV2	Car	LCV	MCV	Average	After policy: HCV1	HCV2	Car	LCV	MCV	Average
Time costs	0.579	0.725	0.262	0.367	0.446	**0.3094**	0.708	0.876	0.303	0.423	0.541	**0.3616**

E3. Total user costs
(vehicle operating+ time costs)

$ per vehicle-km	Before policy: HCV1	HCV2	Car	LCV	MCV	Average	After policy: HCV1	HCV2	Car	LCV	MCV	Average
Total user costs	1.993	3.916	0.517	0.659	1.075	**0.735**	2.011	3.909	0.543	0.689	1.121	**0.761**

E4. Accident costs

Accident type	**kA$/ accid.**
Fatal accident	4332
Serious injury accident	461.7
Other injury accident	27.4
Personal injury accident (av.)	

Unit costs of reported crashes in 100 km/h speed limit areas from EEM Tables A6.21(e)-(g)

E5a. Air pollution costs

Air pollutants' unit costs	$/t	
Carbon monoxide CO	0.038	
Hydrocarbons HC	12.0	
Oxides of nitrogen NOx	23.9	
Particles PM	3804	
Carbon dioxide CO2	40.0	Unit cost specified in EEM Section A9.7

Other costs based on unit costs in Table 5.3 in Austroads AGPE04/08 (in NZ$), but only 1% reflecting emissions in rural area

E5b. Noise pollution costs

Unit costs of noise pollution	$/year	
Noise zone 55 to 65 dB		Treated as zero in rural areas in Table 5.1 of Austroads AGPE04/08
Noise zone 65 to 70 dB		
Noise zone >70 dB		

Base VOC with additional for grade on % of vkt applicable on link [calculated at row 59]

Additional VOC for stops and curves [calculates total additional below and converts to $ per veh-km in row 70]

Cruise speed, km/h	89.4	88.5	95.7	95.7	87.7		70	70	80	80	70

F. Calculation of impacts

F1. Vehicle operating costs

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	Total	HCV1	HCV2	Car	LCV	MCV	Total
Vehicle operating costs	231,810	397,079	689,393	89,056	100,323	**1,507,661**	199,065	347,787	636,993	78,914	88,217	**1,350,977**

Additional VOC and travel time for stops and slowing for curves

Category 5 roads (Factors for density of stops and curves per 100 km)

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	Total	HCV1	HCV2	Car	LCV	MCV	Total
additional	20,773	39,835	21,788	3,995	6,437	**92,829**	4,620	8,347	8,511	1,492	1,585	**24,555**
% added	9.84%	11.15%	3.26%	4.70%	6.86%	6.56%	2.38%	2.46%	1.35%	1.93%	1.83%	1.85%

F2a. Travel time

	Before policy, vehicle-hours/day						After policy, vehicle-hours/day					
	HCV1	HCV2	Car	LCV	MCV	Total	HCV1	HCV2	Car	LCV	MCV	Total
Total travel time on link	4,867	3,704	79,584	8,888	4,903	**101,946**	5,957	4,478	91,960	10,239	5,941	**118,575**

	Before policy, vehicle-hours/day						After policy, vehicle-hours/day					
	HCV1	HCV2	Car	LCV	MCV	Total	HCV1	HCV2	Car	LCV	MCV	Total
additional	293	239	4,572	553	240	**5,897**	115	96	2,227	268	99	**2,806**
@free speed	4,574	3,465	75,012	8,335	4,663	**96,049**	5,842	4,381	89,733	9,970	5,842	**115,769**
% added	6.41%	6.89%	6.10%	6.63%	5.16%	6.14%	1.98%	2.20%	2.48%	2.69%	1.70%	2.42%

F2b. Travel time costs

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	Total	HCV1	HCV2	Car	LCV	MCV	Total
Total travel time costs	86,388	81,168	686,646	106,848	66,612	**1,027,661**	105,734	98,115	793,424	123,091	80,713	**1,201,077**

Base travel time = length/cruise speed*AADT

Additional travel time calculated above (for total stops and curves on link)

Total travel time [use to calculate average speed on link: row 24 in Outlining]

F3. Consumer surplus

	Input data, before policy						Input data, after policy					
	HCV1	HCV2	Car	LCV	MCV	Average	HCV1	HCV2	Car	LCV	MCV	Average
Total user costs, $/veh.km	1.993	3.916	0.517	0.659	1.075	**0.735**	2.011	3.909	0.543	0.689	1.121	0.761
Mio veh.kms/year	149	112	2,620	291	149	**3,322**	149	112	2,620	291	149	**3,322**

	Change in consumer surplus					Total
k$/year	2754	-857	67655	8605	6847	**85005**

F4a. Casualty accident rates

	Before policy, crashes/year						After policy, crashes/year						
	HCV1	HCV2	Car	LCV	MCV	Total	HCV1	HCV2	Car	LCV	MCV	Total	
Crash rate per million VKT	0.786	0.786	0.786	0.786	0.786	0.786	0.561	0.569	0.622	0.620	0.576	0.615	**Category 5 roads** adjusted injury crash rate/100M vkt from Summary col. AL

F4b. Casualty accident severity

	Before policy, crashes/year						After policy, crashes/year						
	HCV1	HCV2	Car	LCV	MCV	Average	HCV1	HCV2	Car	LCV	MCV	Average	**Open road State Highway**
Fatal (%)	4.15	4.15	2.06	2.20	4.15	2.33	2.13	2.19	1.25	1.34	2.25	1.37	**Crash injury severity of adjusted injury crashes**
Serious injury (%)	14.46	14.46	12.05	13.24	14.46	12.45	10.73	10.87	9.56	10.55	10.99	9.80	**by vehicle type involved (car, LCV, truck)**
Minor injury (%)	81.39	81.39	85.89	84.55	81.39	85.21	87.14	86.94	89.18	88.11	86.76	88.83	from email from Fergus Tate 12 June 2012

NOTE: Lower injury severity on Motorways (Cat 1)

F4c. Accidents

	Before policy, crashes/year						After policy, crashes/year					
	HCV1	HCV2	Car	LCV	MCV	Total	HCV1	HCV2	Car	LCV	MCV	Total
Fatal accident	4.9	3.6	42.5	5.0	4.9	**61.0**	1.8	1.4	20.4	2.4	1.9	**27.9**
Serious injury accident	17.0	12.7	248.3	30.3	17.0	**325.3**	9.0	6.9	155.8	19.0	9.4	**200.2**
Minor injury accident	95.5	71.7	1,769.8	193.6	95.5	**2,226.1**	73.0	55.4	1,453.2	159.0	74.6	**1,815.0**
Total casualty accidents	117.4	88.0	2,060.6	229.0	117.4	**2,612.3**	83.8	63.7	1,629.4	180.4	85.9	**2,043.2**

F4d. Accident costs

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Fatal accident	21,081	15,811	184,259	21,866	21,081	**264,099**	7,732	6,045	88,381	10,488	8,366	**121,012**
Serious injury accident	7,837	5,878	114,637	13,997	7,837	**150,185**	4,149	3,195	71,943	8,784	4,361	**92,431**
Minor injury accident	2,614	1,960	48,421	5,297	2,614	**60,906**	1,997	1,515	39,758	4,349	2,040	**49,659**
Total casualty accidents	31,532	23,649	347,317	41,160	31,532	**475,190**	13,878	10,754	200,082	23,622	14,767	**263,103**

F5a. Air pollution

	At initial speed, t/year						At final speed, t/year					
Emissions	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Carbon monoxide CO	446	334	23,512	2,612	445	**27,351**	425	319	14507	1612	425	**17,288**
Hydrocarbons HC	61	45	1,356	151	60	**1,672**	47	35	981	109	47	**1,219**
Oxides of nitrogen NOx	1,546	1150	4,468	496	1,522	**9,182**	1,247	936	2801	311	1247	**6,543**
Particles PM	261	193	160	18	255	**886**	201	151	101	11	201	**666**
Carbon dioxide CO2	370,896	635,327	620,453	80,150	160,517	**1,867,344**	318,504	556,460	573,294	71,023	141,147	**1,660,427**

F5b. Air pollution costs

	At initial speed, k$/year						At final speed, k$/year					
Emissions	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Carbon monoxide CO	0.0	0.0	0.9	0.1	0.0	**1.0**	0.0	0.0	0.5	0.1	0.0	**0.6**
Hydrocarbons HC	1	1	16	2	1	**20**	1	0	12	1	1	**15**
Oxides of nitrogen NOx	37	27	107	12	36	**219**	30	22	67	7	30	**156**
Particles PM	991	734	608	68	968	**3,370**	766	575	382	42	766	**2,532**
Carbon dioxide CO2	14,836	25,413	24,818	3,206	6,421	**74,694**	12,740	22,258	22,932	2,841	5,646	**66,417**
Total	**15,865**	**26,175**	**25,550**	**3,287**	**7,426**	**78,304**	**13,537**	**22,856**	**23,393**	**2,892**	**6,442**	**69,120**

F5c. Noise pollution

No. of residents	**Before policy**	**After policy**	**Change**	
Noise zone 55 to 65 dB			0	#DIV/0!
Noise zone 65 to 70 dB			0	#DIV/0!
Noise zone >70 dB			0	#DIV/0!

F5d. Noise pollution costs

	k$/ year			
	Before policy	**After policy**	**Change**	
Noise zone 55 to 65 dB	0	0	0	#DIV/0!
Noise zone 65 to 70 dB	0	0	0	#DIV/0!
Noise zone >70 dB	0	0	0	#DIV/0!
Total	**0**	**0**	**0**	**#DIV/0!**

G. Non-quantified impacts

Noise pollution

Summary of quantified impacts

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Total monetary impact	365,595	528,071	1,748,906	240,351	205,893	**3,088,817**	332,214	479,512	1,653,892	228,520	190,139	**2,884,277**

MANAGING SPEEDS OF TRAFFIC ON EUROPEAN ROADS

Application of the MASTER framework

Ver. 01/99

Reduction of cruise speeds to optimum speeds on Category 5 (Straight Regional Other) roads

H. Net impacts

	Cruise Speed (km/h)	
Trucks (LCV I)	**89.4**	**70**
Cars	**95.7**	**80**

Average speed on link (km/h)	Before	After
Trucks (LCV I)	**84.0**	**68.6**
Cars	**90.2**	**78.1**

H1. Physical impacts

		Before	After	Change	
Total travel time on link, hours/day		101,946	118,575	16,628	16.3 %
Number of Crashes per year		2,612.3	2,043.2	-569.2	-21.8%
Emissions, t/year	Carbon monoxide CO	27351	17288	-10062	-36.8 %
	Hydrocarbons HC	1672	1219	-453.3	-27.1 %
	Oxides of nitrogen NOx	9182	6543	-2639	-28.7 %
	Particles PM	885.9	665.6	-220.33	-24.9 %
	Carbon dioxide CO2	1867344	1660427	-206917	-11.1 %
Residents in area where $L_{Aeq,07-22hrs}$ > 55 d		0	0	0	

Increase/vehicle/100km (mins.) Trucks: **16.0** Cars: **10.3**

Saving p.a. Fatal: **33.0** Serious Inj: **125.1** Other Inj: **411.1**

H2. Monetary impacts

k$/year	**Before**	**After**	**Change**	
Consumer surplus	(N. A.)	(N. A.)		(N. A.)
Vehicle operating costs	1,507,661	1,350,977	-156685	-10.4 %
Time costs	1,027,661	1,201,077	173416	16.9 %
Crash costs	475,190	263,103	-212,087	-44.6%
Air pollution costs	78,304	69,120	-9,184	-11.7 %
Noise costs (not valued)	0	0	0	
Total	**3,088,817**	**2,884,277**		
Change			**-204,540**	**-6.6 %**

H3. Summary of monetary impacts for each cruise speed

kA$/year km/h	70	75	80	85	90	95	100	105	110	115	120	125	130
Consumer surplus	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)
Vehicle operating costs	1,328,366	1,352,386	1,386,985	1,429,042	1,492,454	1,563,186	1,641,669	1,724,360	1,810,984	1,901,297	1,995,080	2,092,138	2,192,292
Time costs	1,322,062	1,239,870	1,168,962	1,109,288	1,061,111	1,023,040	994,018	970,054	950,404	934,435	921,605	911,439	903,521
Crash costs	191,716	234,600	284,979	343,776	411,971	490,608	580,790	683,683	800,512	932,567	1,081,199	1,247,824	1,433,918
Air pollution costs	68,243	69,663	71,738	74,203	78,180	82,671	87,750	92,702	97,937	103,443	109,213	115,239	121,513
Noise costs (not valued)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**2,910,387**	**2,896,519**	**2,912,664**	**2,956,309**	**3,043,716**	**3,159,505**	**3,304,228**	**3,470,800**	**3,659,837**	**3,871,742**	**4,107,097**	**4,366,639**	**4,651,244**
of which:													
Heavy vehicles	**1,001,865**	1,009,455	1,030,252	1,060,725	1,115,583	1,179,584	1,251,172	1,329,955	1,416,395	1,510,673	1,613,012	1,723,673	1,842,954
Cars & light comm. vehs.	1,908,522	1,887,065	**1,882,412**	1,895,584	1,928,133	1,979,921	2,053,055	2,140,845	2,243,441	2,361,069	2,494,086	2,642,966	2,808,290

H4. Monetary impacts for cars and LCVs at each cruise speed

kA$/year km/h	70	75	80	85	90	95	100	105	110	115	120	125	130
Consumer surplus	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)
Vehicle operating costs	693,297	703,260	715,907	731,623	751,341	774,605	802,701	832,135	862,673	894,103	926,230	958,879	991,886
Time costs	1,037,500	972,790	916,515	868,637	828,976	797,129	773,049	752,940	736,222	722,406	711,070	701,847	694,414
Crash costs	152,317	185,224	223,704	268,427	320,107	379,501	447,412	524,685	612,210	710,922	821,800	945,870	1,084,202
Air pollution costs	25,408	25,791	26,286	26,897	27,709	28,686	29,894	31,085	32,336	33,638	34,985	36,371	37,788
Noise costs (not valued)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**1,908,522**	**1,887,065**	**1,882,412**	**1,895,584**	**1,928,133**	**1,979,921**	**2,053,055**	**2,140,845**	**2,243,441**	**2,361,069**	**2,494,086**	**2,642,966**	**2,808,290**

H5. Monetary impacts for heavy vehicles at each cruise speed

kA$/year km/h	70	75	80	85	90	95	100	105	110	115	120	125	130
Consumer surplus	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)
Vehicle operating costs	635,069	649,127	671,078	697,419	741,113	788,581	838,969	892,225	948,311	1,007,194	1,068,850	1,133,258	1,200,406
Time costs	284,562	267,080	252,447	240,652	232,135	225,911	220,970	217,115	214,181	212,029	210,535	209,593	209,107
Crash costs	39,399	49,376	61,275	75,349	91,865	111,107	133,378	158,997	188,302	221,645	259,399	301,954	349,715
Air pollution costs	42,835	43,872	45,452	47,306	50,471	53,985	57,856	61,617	65,601	69,805	74,228	78,868	83,725
Noise costs (not valued)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**1,001,865**	**1,009,455**	**1,030,252**	**1,060,725**	**1,115,583**	**1,179,584**	**1,251,172**	**1,329,955**	**1,416,395**	**1,510,673**	**1,613,012**	**1,723,673**	**1,842,954**

APPENDIX G:
CATEGORY 6 - WINDING REGIONAL CONNECTOR & DISTRIBUTOR ROADS

MANAGING SPEEDS OF TRAFFIC ON EUROPEAN ROADS

Application of the MASTER framework (see separate instructions) Ver. 01/99

LINK-LEVEL ANALYSIS OF THE IMPACTS OF A SPEED MANAGEMENT POLICY

Name of applier: Max Cameron
Institution: Monash University Accident Research Centre

1. Outlining

A. Policy test Reduction of cruise speeds to optimum speeds (not less than 70 km/h) on Category 6 (Winding Regional Other) roads

A1. Length of link 1117.6 km

A2. Flow characteristics

Traffic attributes	Before policy						After policy					
	HCV1	HCV2	Car	LCV	MCV	**Total/ Average**	HCV1	HCV2	Car	LCV	MCV	**Total/ Average**
Cruise speed, km/h	74.9	74.4	79.7	79.7	73.9	**79.1**	70	70	70	70	70	**70.0**
Average of all speeds on link	69.4	68.5	74.1	73.7	69.4		66.1	65.7	67.1	66.9	66.6	
AADT*	82	62	1,480	164	82	**1,870**	82	62	1,480	164	82	**1,870**
Share of traffic	4%	3%	79%	9%	4%	100%	4%	3%	79%	9%	4%	100%
Business trips, %	85	85	30	55	85	**39**	85	85	30	55	85	**39**
Pers. bus. and commuting. trips,	5	5	10	5	5	**9**	5	5	10	5	5	**9**
Leisure trips, %	10	10	60	40	10	**52**	10	10	60	40	10	**52**

*average annual daily traffic volume, vehicles per day

B. Link/network level analysis

This workbook is best suited for link analysis. However, elastic travel demand can be assumed, for the workbook contains formulas for consumer surplus calculation.

C. Deciding on relevant impacts

- [x] Vehicle operating costs
- [x] Travel time
- [x] Accidents
- [x] Air pollution
- [ ] Noise
- [ ] Other

Reduction of cruise speeds to optimum speeds (not less than 70 km/h) on Category 6 (Winding Regional Other) roads

2. Measurement of impacts

D. Impact functions

D1. Vehicle operating costs

VOC running cost models from EEM Table A5.11 for speed and grade (adjustment for stops and curves based on EEM Tables 5.24-33)

D2. Travel time

Function: travel time = link length/free speed of traffic flow (flat straight roads only; adjustment for stops and curves based on EEM Tables 5.24-33)

D3a. Accidents

Injury accidents before = n_{IB} Average speed before = v_B

Injury accidents after = n_{IA} Average speed after = v_A

		Exponent	Value	
Fatal accidents	**$n_{IA} = (v_A/v_B)F * n_{IB}$**	**F**	**4.1**	Rural highway/freeway exponent estimates
Serious injury accidents	**$n_{IA} = (v_A/v_B)S * n_{IB}$**	**S**	**2.6**	from Cameron and Elvik (2010), Table 8
Other injury accidents	**$n_{IA} = (v_A/v_B)O * n_{IB}$**	**O**	**1.1**	

Base emissions functions (g/vkt) from EEM table in Appendix A9.3

Source:		Carbon monoxide CO			Oxides of nitrogen NO_x			Particles PO10		
MASTER Working		A	B	C	A	B	C	A	B	C
Paper R1.2.1,	LV	0.00360	-0.545	25.5	0.000246	-0.0287	1.67	#######	-0.00342	0.153
App. D, p. D-6	HV	0.000647	-0.11	7.31	0.002040	-0.275	17.4	0.000382	-0.0455	2.65

D4. Air pollutant emission coefficients

Cruise speed, km/h	74.9	74.4	79.7	79.7	73.9		70	70	70	70	70	
	At initial speed, g/km						**At final speed, g/km**					
*Emission factors**	HCV1	HCV2	Car	LCV	MCV	Average	HCV1	HCV2	Car	LCV	MCV	Average
Carbon monoxide CO	2.72	2.73	5.55	5.55	2.74	5.21	2.81	2.81	5.03	5.03	2.81	4.77
Hydrocarbons HC	0.33	0.32	0.37	0.37	0.32	0.37	0.31	0.31	0.31	0.31	0.31	0.31
Oxides of nitrogen NO_x	8.32	8.31	1.07	1.07	8.30	1.94	8.22	8.22	0.87	0.87	8.22	1.76
Particles PM	1.39	1.38	0.04	0.04	1.38	0.201	1.34	1.34	0.03	0.03	1.34	0.192
Carbon dioxide CO_2	2715.2	6977.2	221.8	246.6	1107.6	594.6	2621.8	6800.2	212.6	230.0	1078.1	574.6

Emission coefficients for HC not available by vehicle type, only for mix of traffic close to mix outlined here

CO2: EEM function of VOC from row 59 + row 70

CO, Nox, PM: EEM functions with Ding adjustment factors

HC: g/km from 2000 AADT

Flat road 80 kmh	90 kmh
678	739

Adjustment factors for increased emissions due to stops and sharp curves (less than 200m radius) on road

	At initial speed, g/km						**At final speed, g/km**					
	HCV1	HCV2	Car	LCV	MCV		HCV1	HCV2	Car	LCV	MCV	
CO	1.009	1.009	1.125	1.125	1.009		1.009	1.009	1.009	1.009	1.009	
HC	1.008	1.008	1.107	1.107	1.008		1.008	1.008	1.008	1.008	1.008	
NOx	1.009	1.009	1.132	1.132	1.009		1.009	1.009	1.009	1.009	1.009	
PM	1.003	1.003	1.064	1.064	1.003		1.003	1.003	1.003	1.003	1.003	
CO2	Adjusted through VOC adjustments for stops and curves											

Factors for cruise speeds above 100 km/h not feasible on Category 6 roads, so set at 100 km/h factors

D5. Noise pollution

No impact function available; noise pollution assumed small because of negligible human population living in vicinity of rural roads considered

E. Unit prices

	Time cost	VOC	Crash cost	$AUS to $NZ
Base year to 2009 Update factor	1.220	1.000	1.140	1.25

E1. Vehicle operating costs

		Before policy						After policy						
		HCV1	HCV2	Car	LCV	MCV	Average	HCV1	HCV2	Car	LCV	MCV	Average	GR
	a	-75.602	-263.900	24.616	15.852	20.230		-75.602	-263.900	24.616	15.852	20.230		
	c	263.07	469.66	43.489	64.641	87.808		263.07	469.66	43.489	64.641	87.808		
	e	-101.34	-159.79	-21.157	-30.064	-39.668		-101.34	-159.79	-21.157	-30.064	-39.668		
	h	11.615	17.174	2.5663	3.6463	4.8935		11.615	17.174	2.5663	3.6463	4.8935		
Zero grade VOC (cents/km)		105.89	167.03	24.84	28.59	53.46		103.58	164.26	24.30	27.45	52.54		
$ per vehicle-km														
Vehicle Operating Costs (VOC)		1.558	4.028	0.236	0.257	0.647	**0.438**	1.531	3.988	0.230	0.245	0.637	**0.430**	
100	b	82.435	2722.4	-44.832	-109.65	-70.181		82.435	2722.4	-44.832	-109.65	-70.181		
####	d	9566.1	15069	-445.63	-118.58	2731.4		9566.1	15069	-445.63	-118.58	2731.4		
100	f	-65.136	-1446.2	38.558	68.678	55.741		-65.136	-1446.2	38.558	68.678	55.741		
####	g	-608.65	-1306	17.595	12.105	-165.84		-608.65	-1306	17.595	12.105	-165.84		
1000	i	-48.388	1796.9	-61.237	-99.936	-147.07		-48.388	1796.9	-61.237	-99.936	-147.07		
1000	j	171.01	488.06	12.523	15.75	58.615		171.01	488.06	12.523	15.75	58.615		
Rolling: Additional VOC for GR4-6		35.17	181.10	-1.25	-2.81	7.23		34.95	180.30	-1.27	-2.84	7.19		5
Mount'ous: Additional VOC for GR7-11		96.61	413.28	-1.41	-3.27	23.82		95.74	410.81	-1.52	-3.41	23.60		9
"Flat": Additional VOC for GR1-3		4.23	38.89	-0.33	-0.86	0.24		4.25	38.72	-0.32	-0.85	0.27		2
Additional VOC for stops/curves		0.139	0.332	0.011	0.017	0.045	**0.029**	0.108	0.262	0.006	0.010	0.037	**0.021**	
(added in row 118, not row 59)		8.94%	8.25%	4.53%	6.60%	6.98%	**6.61%**	7.04%	6.56%	2.78%	4.28%	5.77%	**4.87%**	

Source: EEM Table A5.11

Zero grade VOC plus additional VOC for grade (on % vkt applicable)
No update factor applied (because 1 for VOC)

Category 6 roads

% of VKT in terrain

HV	LV
70.55%	68.85%
25.80%	28.19%
3.61%	2.95%

E2a. Time costs per hour

Value of travel time	$ per hour				
	HCV1	HCV2	Car	LCV	MCV
Business trips, %	55.2	68.6	48.2	49.2	41.8
Pers. bus. and commuting. trips,	12.4	12.4	14.5	14.5	12.4
Leisure trips, %	11.0	11.0	12.9	12.9	11.0
Average	**48.6**	**60.0**	**23.6**	**32.9**	**37.2**

Travel time values at June 2002 from EEM Tables A4.1-2 and vehicle occupancy rates from EEM Table A2.5

E2b. Time costs per kilometre

	$ per vehicle-km											
	Before policy						After policy					
	HCV1	HCV2	Car	LCV	MCV	Average	HCV1	HCV2	Car	LCV	MCV	Average
Time costs	0.701	0.876	0.319	0.447	0.536	**0.3748**	0.736	0.914	0.352	0.492	0.559	**0.4089**

E3. Total user costs
(vehicle operating+ time costs)

	$ per vehicle-km											
	Before policy						After policy					
	HCV1	HCV2	Car	LCV	MCV	Average	HCV1	HCV2	Car	LCV	MCV	Average
Total user costs	2.259	4.904	0.555	0.704	1.183	**0.813**	2.267	4.903	0.582	0.737	1.196	**0.839**

E4. Accident costs

Accident type	**kA$/ accid.**
Fatal accident	4332
Serious injury accident	461.7
Other injury accident	27.4
Personal injury accident (av.)	

Unit costs of reported crashes in 100 km/h speed limit areas from EEM Tables A6.21(e)-(g)

E5a. Air pollution costs

Air pollutants' unit costs	$/t
Carbon monoxide CO	0.038
Hydrocarbons HC	12.0
Oxides of nitrogen NOx	23.9
Particles PM	3804
Carbon dioxide CO_2	40.0

Unit cost specified in EEM Section A9.7

Other costs based on unit costs in Table 5.3 in Austroads AGPE04/08 (in NZ$), but only 1% reflecting emissions in rural area

E5b. Noise pollution costs

Unit costs of noise pollution	$/year
Noise zone 55 to 65 dB	
Noise zone 65 to 70 dB	
Noise zone >70 dB	

Treated as zero in rural areas in Table 5.1 of Austroads AGPE04/08

Base VOC with additional for grade on % of vkt applicable on link [calculated at row 59]

Additional VOC for stops and curves [calculates total additional below and converts to $ per veh-km in row 70]

Cruise speed, km/h	74.9	74.4	79.7	79.7	73.9	70	70	70	70	70

F. Calculation of impacts

F1. Vehicle operating costs

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Vehicle operating costs	56,802	109,470	148,774	18,382	23,172	**356,600**	54,848	106,693	142,605	17,141	22,554	**343,841**

Additional VOC and travel time for stops and slowing for curves

Category 6 roads (Factors for density of stops and curves per 100 km)

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
additional	4,661	8,346	6,441	1,138	1,511	**22,097**	3,606	6,569	3,862	704	1,230	**15,972**
% added	8.94%	8.25%	4.53%	6.60%	6.98%	6.61%	7.04%	6.56%	2.78%	4.28%	5.77%	4.87%

F2a. Travel time

	Before policy, vehicle-hours/day						After policy, vehicle-hours/day					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Total travel time on link	1,322	1,004	22,313	2,494	1,321	**28,453**	1,388	1,047	24,641	2,747	1,377	**31,200**

	Before policy, vehicle-hours/day						After policy, vehicle-hours/day					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
additional	97	79	1,560	188	80	**2,005**	78	65	1,013	121	67	**1,344**
@free speed	1,224	924	20,753	2,306	1,241	**26,448**	1,310	983	23,629	2,625	1,310	**29,857**
% added	7.94%	8.59%	7.52%	8.15%	6.46%	7.58%	5.94%	6.59%	4.29%	4.62%	5.11%	4.50%

F2b. Travel time costs

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Total travel time costs	23,456	21,996	192,516	29,979	17,948	**285,895**	24,634	22,950	212,604	33,021	18,707	**311,916**

Base travel time = length/cruise speed*AADT

Additional travel time calculated above (for total stops and curves on link)

Total travel time [use to calculate average speed on link: row 24 in Outlining]

F3. Consumer surplus

	Input data, before policy						**Input data, after policy**					
	HCV1	HCV2	Car	LCV	MCV	**Average**	HCV1	HCV2	Car	LCV	MCV	**Average**
Total user costs, $/veh.km	2.259	4.904	0.555	0.704	1.183	**0.813**	2.267	4.903	0.582	0.737	1.196	0.839
Mio veh.kms/year	33	25	604	67	33	**763**	33	25	604	67	33	**763**

	Change in consumer surplus					**Total**
k$/year	280	-46	16497	2234	422	**19387**

F4a. Casualty accident rates

	Before policy, crashes/year						After policy, crashes/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Crash rate per million VKT	0.890	0.890	0.890	0.890	0.890	0.890	0.808	0.816	0.750	0.748	0.824	0.758

Category 6 roads adjusted injury crash rate/100M vkt from Summary col. AL

F4b. Casualty accident severity

	Before policy, crashes/year						After policy, crashes/year					
	HCV1	HCV2	Car	LCV	MCV	**Average**	HCV1	HCV2	Car	LCV	MCV	**Average**
Fatal (%)	4.15	4.15	2.06	2.20	4.15	2.33	3.46	3.52	1.44	1.54	3.59	1.72
Serious injury (%)	14.46	14.46	12.05	13.24	14.46	12.45	13.35	13.46	10.20	11.24	13.57	10.72
Minor injury (%)	81.39	81.39	85.89	84.55	81.39	85.23	83.19	83.02	88.36	87.22	82.84	87.56

Open road State Highway

Crash injury severity of adjusted injury crashes

by vehicle type involved (car, LCV, truck)

from email from Fergus Tate 12 June 2012

NOTE: Lower injury severity on Motorways (Cat 1)

F4c. Accidents

	Before policy, crashes/year						After policy, crashes/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Fatal accident	1.2	0.9	11.1	1.3	1.2	**15.8**	0.9	0.7	6.5	0.8	1.0	**9.9**
Serious injury accident	4.3	3.2	64.7	7.9	4.3	**84.5**	3.6	2.8	46.2	5.6	3.7	**62.0**
Minor injury accident	24.2	18.2	461.5	50.5	24.2	**578.6**	22.5	17.0	400.1	43.8	22.8	**506.2**
Total casualty accidents	29.8	22.3	537.3	59.7	29.8	**678.9**	27.1	20.5	452.8	50.2	27.6	**578.1**

F4d. Accident costs

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Fatal accident	5,350	4,013	48,047	5,702	5,350	**68,463**	4,054	3,125	28,222	3,349	4,284	**43,035**
Serious injury accident	1,989	1,492	29,893	3,650	1,989	**39,012**	1,668	1,273	21,332	2,605	1,727	**28,605**
Minor injury accident	663	498	12,626	1,381	663	**15,832**	616	465	10,947	1,197	625	**13,850**
Total casualty accidents	8,003	6,002	90,566	10,733	8,003	**123,307**	6,338	4,864	60,501	7,151	6,636	**85,490**

F5a. Air pollution

	At initial speed, t/year						At final speed, t/year					
Emissions	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Carbon monoxide CO	91	69	3,349	372	92	**3,972**	94	70	3040	338	94	**3,636**
Hydrocarbons HC	11	8	226	25	11	**281**	10	8	188	21	10	**237**
Oxides of nitrogen NOx	279	209	646	72	278	**1,482**	275	206	528	59	275	**1,344**
Particles PM	47	35	23	3	46	**153**	45	34	20	2	45	**146**
Carbon dioxide CO2	90,883	175,153	133,897	16,544	37,075	**453,551**	87,757	170,709	128,344	15,426	36,086	**438,323**

F5b. Air pollution costs

	At initial speed, k$/year						At final speed, k$/year					
Emissions	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Carbon monoxide CO	0.0	0.0	0.1	0.0	0.0	**0.1**	0.0	0.0	0.1	0.0	0.0	**0.1**
Hydrocarbons HC	0	0	3	0	0	**3**	0	0	2	0	0	**3**
Oxides of nitrogen NOx	7	5	15	2	7	**35**	7	5	13	1	7	**32**
Particles PM	177	132	88	10	175	**582**	171	128	78	9	171	**556**
Carbon dioxide CO2	3,635	7,006	5,356	662	1,483	**18,142**	3,510	6,828	5,134	617	1,443	**17,533**
Total	**3,819**	**7,143**	**5,462**	**674**	**1,665**	**18,763**	**3,688**	**6,961**	**5,226**	**627**	**1,621**	**18,124**

F5c. Noise pollution

No. of residents	**Before policy**	**After policy**	**Change**	
Noise zone 55 to 65 dB			0	#DIV/0!
Noise zone 65 to 70 dB			0	#DIV/0!
Noise zone >70 dB			0	#DIV/0!

F5d. Noise pollution costs

	k$/ year			
	Before policy	**After policy**	**Change**	
Noise zone 55 to 65 dB	0	0	0	#DIV/0!
Noise zone 65 to 70 dB	0	0	0	#DIV/0!
Noise zone >70 dB	0	0	0	#DIV/0!
Total	**0**	**0**	**0**	**#DIV/0!**

G. Non-quantified impacts

Noise pollution

Summary of quantified impacts

	Before policy, k$/year						After policy, k$/year					
	HCV1	HCV2	Car	LCV	MCV	**Total**	HCV1	HCV2	Car	LCV	MCV	**Total**
Total monetary impact	92,079	144,612	437,319	59,768	50,788	**784,565**	89,508	141,468	420,936	57,940	49,518	**759,370**

MANAGING SPEEDS OF TRAFFIC ON EUROPEAN ROADS

Application of the MASTER framework

Ver. 01/99

Reduction of cruise speeds to optimum speeds (not less than 70 km/h) on Category 6 (Winding Regional Other) roads

H. Net impacts

	Cruise Speed (km/h)	
Trucks (LCV I)	**74.9**	**70**
Cars	**79.7**	**70**

Average speed on link (km/h)	Before	After
Trucks (LCV I)	**69.4**	**66.1**
Cars	**74.1**	**67.1**

H1. Physical impacts

		Before	After	Change	
Total travel time on link, hours/day		28,453	31,200	2,747	9.7 %
Number of Crashes per year		678.9	578.1	-100.8	-14.9%
Emissions, t/year	Carbon monoxide CO	3972	3636	-337	-8.5 %
	Hydrocarbons HC	281	237	-43.6	-15.5 %
	Oxides of nitrogen NOx	1482	1344	-139	-9.4 %
	Particles PM	153.1	146.1	-7.01	-4.6 %
	Carbon dioxide CO2	453551	438323	-15227	-3.4 %
Residents in area where $L_{Aeq,07\text{-}22hrs}$ > 55 d		0	0	0	

Increase/vehicle/100km (mins.) Trucks: **4.3** Cars: **8.4**

Saving p.a. Fatal: **5.9** Serious Inj: **22.5** Other Inj: **72.4**

H2. Monetary impacts

k$/year	**Before**	**After**	**Change**	
Consumer surplus	(N. A.)	(N. A.)		(N. A.)
Vehicle operating costs	356,600	343,841	-12759	-3.6 %
Time costs	285,895	311,916	26021	9.1 %
Crash costs	123,307	85,490	-37,817	-30.7%
Air pollution costs	18,763	18,124	-640	-3.4 %
Noise costs (not valued)	0	0	0	
Total	**784,565**	**759,370**		
Change			**-25,195**	**-3.2 %**

H3. Summary of monetary impacts for each cruise speed

kA$/year	km/h 70	75	80	85	90	95	100	105	110	115	120	125	130
Consumer surplus	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)
Vehicle operating costs	343,841	353,249	367,159	383,878	407,163	432,722	460,672	490,067	520,831	552,899	586,208	620,704	656,333
Time costs	311,916	295,869	282,501	272,354	265,608	261,325	259,248	258,322	258,360	259,198	260,693	262,719	265,158
Crash costs	85,490	106,272	130,923	159,935	193,833	233,178	278,559	330,603	389,969	457,349	533,470	619,092	715,013
Air pollution costs	18,124	18,686	19,533	20,499	21,969	23,574	25,283	27,028	28,868	30,801	32,826	34,940	37,140
Noise costs (not valued)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**759,370**	**774,076**	**800,116**	**836,667**	**888,573**	**950,798**	**1,023,762**	**1,106,020**	**1,198,027**	**1,300,247**	**1,413,197**	**1,537,454**	**1,673,643**
of which:													
Heavy vehicles	**280,494**	288,388	302,132	319,788	344,916	373,425	404,945	439,556	477,436	518,727	563,589	612,191	664,719
Cars & light comm. vehs.	**478,876**	485,688	497,984	516,879	543,657	577,374	618,817	666,464	720,592	781,519	849,608	925,263	1,008,924

H4. Monetary impacts for cars and LCVs at each cruise speed

kA$/year	km/h 70	75	80	85	90	95	100	105	110	115	120	125	130
Consumer surplus	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)
Vehicle operating costs	159,745	163,257	167,423	172,558	179,251	186,866	195,743	204,941	214,391	224,027	233,792	243,627	253,481
Time costs	245,625	232,807	221,887	213,297	207,294	203,200	201,021	199,753	199,250	199,385	200,046	201,136	202,566
Crash costs	67,652	83,634	102,521	124,676	150,488	180,368	214,753	254,105	298,908	349,674	406,938	471,259	543,224
Air pollution costs	5,854	5,990	6,154	6,347	6,624	6,939	7,299	7,664	8,043	8,433	8,833	9,240	9,653
Noise costs (not valued)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**478,876**	**485,688**	**497,984**	**516,879**	**543,657**	**577,374**	**618,817**	**666,464**	**720,592**	**781,519**	**849,608**	**925,263**	**1,008,924**

H5. Monetary impacts for heavy vehicles at each cruise speed

kA$/year	km/h 70	75	80	85	90	95	100	105	110	115	120	125	130
Consumer surplus	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)	(N. A.)
Vehicle operating costs	184,095	189,991	199,737	211,320	227,911	245,855	264,929	285,125	306,440	328,871	352,417	377,076	402,852
Time costs	66,291	63,062	60,613	59,057	58,313	58,125	58,226	58,568	59,109	59,813	60,647	61,582	62,592
Crash costs	17,838	22,638	28,402	35,259	43,346	52,810	63,806	76,498	91,061	107,675	126,532	147,833	171,788
Air pollution costs	12,270	12,697	13,380	14,152	15,345	16,634	17,984	19,364	20,825	22,368	23,993	25,699	27,487
Noise costs (not valued)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**280,494**	**288,388**	**302,132**	**319,788**	**344,916**	**373,425**	**404,945**	**439,556**	**477,436**	**518,727**	**563,589**	**612,191**	**664,719**