IDS

Pavement Cost Impact Assessment from Increased Axle Loads on 2 and 3-Axle Buses – *VDAM Bus Amendment March 2016*

March 2016

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Abbreviations

50MAX	High productivity motor vehicle maximum laden mass 50 tonnes
AUSTROADS	Australian Association of State Roading Authorities. The authority responsible for the development of road design standards commonly used in New Zealand and Australia
CAM	Cost allocation model developed by MoT in order to allocate the total NLTP expenditure across various areas of expenditure
CoF	Certificate of fitness
dTIMS	Deighton's Total Infrastructure Management System
ESA	Equivalent Standard Axle. Single axle with dual wheels loaded to a total mass of 8.2 tonnes and 750 KPa tyre pressure.
FAR	Financial Assistance Rate
GML	General mass limits
GVM	Gross vehicle mass
HCV	Heavy commercial Vehicle. A vehicle having at least one axle with dual wheels and/or having more than two axles – over 3.5 tonnes gross laden weight
HCV1	Heavy Commercial Vehicle 1. A rigid truck with or without a trailer, or an articulated vehicle, with 3 or 4 axles in total
HCV2	Heavy Commercial Vehicle 2. A truck and trailer, or articulated vehicle with or without a trailer, with 5 or more axles in total.
HPMV	High productivity motor vehicle. A heavy vehicle with or without a trailer that complies with the maximum envelope of dimension and mass limits prescribed in the VDAM Rule Amendment of 2010
HVKT	Heavy vehicle kilometres travelled. The length of a road section multiplied by the number of heavy vehicles using it
FWD	Falling weight deflectometer. A device measuring the pavement response to a force pulse that is applied to the road surface by a specially designed loading system which represents the dynamic short-term loading of a passing heavy wheel load. The deflection bowl response of the pavement is measured with a set of seven precision geophones at a range of set distances from the loading plate
MoT	Ministry of Transport New Zealand
NLTP	National Land Transport Programme
RAMM	Road Asset Maintenance Management. Computer software system used by road controlling authorities in managing their road networks
VDAM	Vehicle Dimension and Mass Rule. Land Transport Rule that outlines specific requirements for dimension and mass limits for vehicles operating on New Zealand Roads
VKT	Vehicle kilometres travelled. The length of a road section multiplied by the number of vehicles using it
WIM	Weigh in Motion. In-road device measuring vehicle weight at normal highway speeds, count and classify vehicles numbers

Where reference is made to vehicles in this report it means buses.

Executive Summary

The purpose of this study is to evaluate the additional pavement wear related costs that could be attributed to an increase in the allowable axle group loads on 2 and 3-axle buses.

The analysis shows that a rise in pavement wear can be expected across the national road network under the proposed increased axle group loads for 2 and 3-axle buses. This study quantifies the impact on pavement wear in terms of the relative cost increase associated with pavement maintenance resulting from the different load scenarios based on the assumptions stipulated in the methodology hereafter.

The data shows a current bus fleet of approximately 9,000 vehicles. They travel approximately 15% of the total vehicle kilometre travelled (VKT) for heavy commercial vehicles (HCVs) with a gross vehicle mass of greater > 9 tonnes as these are the vehicles doing the damage to the roads.

The predicted costs are presented for three different scenarios in potential uptake of the increased mass limits i.e. a quarter, a third and half of the total bus fleet, which represents 3.6%, 4.7% and 7.2% of the total travelled distance for each of the scenarios respectively. The calculations used to estimate the increase in pavement wear are based on the vehicles being operated at their permitted maximum masses, and as such, will produce an upper bound cost as not all heavy vehicle kilometres travelled (HVKT) are at the maximum limits.

The biggest unknown is the length of local roads in the weak and medium strength categories that will be subjected to the increase in loading – the impact is known but the total scale/extent is unknown. A sensitivity analysis showed that the damage cost doubles with doubling of the proportion of weaker pavements on the network.

The predicted cost increase calculated for each of the above scenarios takes into account the efficiency of the higher capacity bus by recognising that fewer trips will be required to transport the same number of passengers.

The increase in expenditure for the state highway network is funded exclusively from the National Land Transport Programme (NLTP) whilst the NLTP funds approximately 50% of the local road expenditure and the local authorities fund the balance via their rating base. The impact on the local roads has a lower degree of confidence due to the uncertainty and assumptions in the knowledge base with respect to the condition of the local roads.

The results of the study are summarised in tables Table 0-1and Table 0-2 hereafter.

Table 0-1 Predicted cost increase for 3-Axle Buses

Analysis vehicle	Load Scenario	Rear Group Limit (tonnes)	Rear Group Load Share Split	Predicted Increase in Cost ($M)		
				State Highways	Local Roads	Total
All 3-axle buses	General Mass Limits	13.6	60/40%	-	-	-
		14.5	55/45%	0.2 0.3 0.4	0.5 0.6 0.8	0.7 (25%) 0.9 (33%) 1.2 (50%)
All 3-axle urban and rural buses including double deck buses (66 seaters)	As per VDAM 2015 Schedule 2, Part C	16.0	60/40%	5.7 7.1 9.9	8.9 11.1 15.5	14.6 18.2 25.4
		16.0	55/45%	3.1 3.9 5.4	5.0 6.2 8.7	8.1 10.1 14.1

Table 0-2 Predicted cost increase for 2-Axle Buses

Analysis vehicle	Load Scenario	Rear Group Limit (tonnes)	Predicted Increase in Cost ($M)		
			State Highways	Local Roads	Total
All 2-axle buses – rear axle set	General Mass Limits	8.2	-	-	-
	Increase to 8.8 tonnes	8.8	3.4 4.2 5.9	5.6 7.0 9.8	9.0 (25%) 11.2 (33%) 15.7 (50%)

1. Introduction

The 2010 amendment to the Vehicle Dimensions and Mass Rule (VDAM) allows for heavy vehicles to operate under permit at sizes and weights above the standard legal maxima on approved roads within New Zealand. The provision for the larger vehicles, designated as High Productivity Motor Vehicles (HPMVs) was aimed at increasing freight productivity across the country.

In response to a request from Auckland Transport and Wellington City Council, a small change to the VDAM legislation in 2015 allows increased rear axle loading for high capacity urban buses as defined in Schedule 2 Part C of the amended rule.

The success of this activity has prompted additional proposals from industry which can be summarised as follows:

- Increased axle loads on intercity buses to allow 3-axle double decker buses to operate long distance at the limits defined in Schedule 2 Part C of VDAM;
- Similar increased axle loads on all 3-axle buses for both urban and rural buses;
- An increase to 16.0 tonnes on the rear axle group of all 3-axle bus;
- An increase to 8.8 tonnes on the rear axle of all 2-axle buses with dual-tyred rear axles.

The purpose of this study is to evaluate the cost impact of pavement maintenance from increased axle loads on two and three axle buses. NZ Transport Agency (NZTA) has engaged IDS to undertake this study on the national state highway and local road networks.

2. Project Objective

The primary objective of this study is to evaluate the additional pavement wear related costs that could be attributed to an increase in the allowable axle group loads on two and three-axle buses.

3. Report structure

The study results are presented and summarised hereafter. The study methodology, information used and assumptions made are included in Appendix A to this report.

4. Study Outcome

4.1 Assumptions

i) A whole of country analysis was conducted for the state highway and local road networks. This gives a cost impact for the NZTA and a total cost impact for the local authorities. The datasets used for the state highway network (refer to Appendix A) are considered to be reliable, given the type and coverage of measured traffic data across the state highway network, this implies a higher degree of confidence in the cost implications for NZTA. The quality and extent of pavement condition and traffic data for the local road networks varies between local authorities and as such, the metrics developed for the state highway data have been used to fill information/data gaps in the local road datasets. The costs reported for the local roads include the FAR subsidy from the NLTP, this is on average 50% of the total cost.

ii) The reported increases in costs are for the road wear component of the MoT CAM, the road wear component costs have been assessed by the MoT to be approximately 20% of the maintenance and operation costs.

iii) The calculations assumed that the HVKT value is with the buses loaded to their gross mass limits (GML) or increased axle limits. This will produce an upper bound estimate of the costs. Data from the NZTA and Ministry of Transport (MoT) show that the HVKT assigned to buses is approximately 15% of the total HVKT figure.

iv) In order to determine the impact of a specific change to the axle limits for a 2 or 3- axle bus, an assessment of the percentage or distance of the total HVKT for the specific bus is made. This allows the impact of the increased axle limits for the specific vehicle to be assessed. This study analysed three different scenarios in potential uptake of the increased mass limits i.e. a quarter, a third and half of the total bus fleet, which represents 3.6%, 4.7% and 7.2% of the total travelled distance for each of the scenarios respectively.

v) The calculations used to estimate the increase in pavement wear are based on the vehicles being operated at their permitted maximum masses, and as such, will produce an upper bound cost as not all HVKT are at the maximum limits.

vi) In addition it is assumed that the passenger task remains constant, i.e. an increase in the mass limit for the specific bus configuration will result in fewer trips. For each type of bus assessed, an estimate of the tare weight was made; this allows the net passenger mass to be determined for the general mass limits and increased axle load cases. It has been assumed that the bus tare weight remains constant for the different scenarios. The efficiency gain is based on the difference in the net weights for the various cases.

vii) This analysis makes no distinction between single and double decker buses, it is driven by the axle configuration of the vehicle and allowable axle group load limits. Analysis for double decker buses can be carried out by specifying the number of VKT for that particular vehicle.

viii) The study results are summarised for the state highway road network and the local roads in two separate tables below. These tables show the expected pavement wear related cost per year for each of the buses assessed, and the cost difference for buses with increased axle loads and those loaded to the current GML limits. Detailed outputs are presented in Appendix A.

ix) A whole of country analysis was conducted for the state highway and local road networks. This gives a cost impact for the NZTA and a total cost estimate for the local authorities.

4.2 Results

The increase in damage cost predicted for the state highway and local road networks are presented in Table 4-1and Table 4-2 below.

The results are grouped for each bus type under consideration (2 or 3-axle bus) and further grouped by the respective load split on the rear axle of each bus. The efficiency of the freight task is as a result of the increase in payload for the higher mass vehicles. The kilometres travelled by each bus type takes into account the freight task efficiency and are based on the assumption that one third of the current bus fleet will convert to the proposed increased loads. Results for the three different uptake scenarios of increased mass limits i.e. a quarter, a third and half of the total bus fleet are included in Appendix A.

The difference in damage cost is calculated for each axle group analysed compared to the standard vehicle in the relevant group that meets the 2010 VDAM gross mass limits.

Table 4-1 National State Highway – Predicted Damage Cost Increase (33% uptake)

							Difference in Damage cost cf current load		
Vehicle[1]	**GVM**	**Steer Axle**	**Rear axle**	**Eff.[2]**	**km travelled per year (million km)[3]**	**Damage cost per year ($M)**	**$M per Year**	**$ per veh / km**	**Increase in cost**
3-Axle Bus (60/40 split on rear axle)									
Current	19600	6000	13600	-	75.77	9.90	-	-	-
New	22000	6000	16000	81%	61.17	16.99	7.09	0.120	72%
3-Axle Bus (55/45 split on rear axle)									
Current	20500	6000	14500	-	75.77	10.20	-	-	-
New	22000	6000	16000	88%	66.64	14.08	3.88	0.07	38%
2-Axle Bus									
Current	14200	6000	8200	-	75.77	8.39	-	-	-
New	14800	6000	8800	94%	71.13	12.63	4.24	0.06	51%

1. Current vehicle complies with the 2010 Gross Mass Limits
2. Reduction in distance travelled due to increase in payload
3. Based on an uptake of 33% to increased axle loads – refer to Appendix A for other scenarios

Table 4-2 All Local Roads – Predicted Damage Cost Increase (33% uptake)

							Difference in Damage cost cf current load		
Vehicle[1]	GVM	Steer Axle	Rear axle	Eff.[2]	km travelled per year (million km)[3]	Damage cost per year ($M)	$M per Year	$ per veh / km	Increase in cost
3-Axle Bus (60/40 split on rear axle)									
Current	19600	6000	13600	-	29.46	18.78	-	-	-
New	22000	6000	16000	81%	23.79	29.87	11.09	0.50	59%
3-Axle Bus (55/45 split on rear axle)									
Current	20500	6000	14500	-	29.46	19.38	-	-	-
New	22000	6000	16000	88%	25.92	25.59	6.21	0.29	32%
2-Axle Bus									
Current	14200	6000	8200	-	29.46	15.56	-	-	-
New	14800	6000	8800	94%	27.66	22.54	6.98	0.27	45%

1. Current vehicle complies with the 2010 Gross Mass Limits
2. Reduction in distance travelled due to increase in payload
3. Based on an uptake of 33% of increased axle loads – refer to Appendix A for other scenarios

Based on experience gained from the CAPTIF and knowledge of the network performance following the introduction of the HPMV regulations, pavement performance following a loading increase can be partitioned into three categories:

1. Weak pavements – prior to a loading change these pavements would be showing an acceptable, but probably elevated rate of deterioration (or no load-associated deterioration for low volume roads). After a loading change they will undergo a rapid increase in deterioration leading to a need for early/immediate rehabilitation. This rapid failure will be as a result of poor drainage, materials or insufficient pavement depths.
2. Medium strength pavements – prior to a loading change these pavements would have been showing an acceptable rate of deterioration. After a loading change they will undergo a step change in the pavement condition, but will stabilise to a constant deterioration rate again. In the short-medium a smoothing/rut filling treatment is likely to be needed. These pavements are likely to have acceptable to good drainage and acceptable materials and pavement depths.
3. Strong pavements – prior to a loading change these pavements will be showing little or no deterioration. After a loading change they will continue to show little or no change. These pavements will have good drainage and good materials and sufficient pavement depth.

Previous mass related changes to the VDAM rules for HPMVs have been incremental, individual axle limits have been increased by 6-9% and axle group limits have been increased by 3-10%, this has allowed the impact of increased pavement damage to be managed through network restrictions and the reallocation of maintenance budgets/programmes. However if larger changes in allowable axle/group limits are permitted, then the impact on pavement wear is likely to be much greater than it has been over the first five years of HPMV operations. Such large changes in axle loading will have a significant impact on weaker pavements that have been constructed in shallow pavements

and with marginal aggregates, and may even result in rapid failure on some sections of road especially on the local authority network.

The methodology used to assess the additional pavement wear related costs that could be attributed to an increase in the allowable axle group loads is outlined in Appendix A.

4.3 Sensitivity Analysis

The biggest unknown is the length of local roads in the weak and medium strength categories that will be subjected to the increase in loading – the impact is known but the total scale/extent is unknown.

The sensitivity of the damage cost to pavement strength was tested by doubling the proportion of the weaker pavements with remaining life < 250,000 ESAs across the state highway and local authority networks.

The results are summarised in Table 4-3 and Table 4-4 and show the predicted increase in damage cost per bus type for the assumed distribution of pavement classes and for a revised distribution with double the length of weaker pavements. The results shown are for an assumed uptake of one third of the bus fleet to the proposed increased axle loads listed below.

The results show that the damage cost doubles with doubling of the length of weaker pavements on the network.

Table 4-3 Damage Cost Sensitivity (3-Axle Buses) (33% uptake)

Analysis vehicle	Load Scenario	Rear Group Limit (tonnes)	Rear Group Load Share Split	Predicted Increase in Cost ($M)		
				State Highways	Local Roads	Total
All 3-axle buses	General Mass Limits	13.6	60/40%	-	-	-
		14.5	55/45%	0.3 / 0.6	0.6 / 1.1	0.9 / 1.6
All 3-axle urban and rural buses including double deck buses (66 seaters)	As per VDAM 2015 Schedule 2, Part C	16.0	60/40%	7.1 / 14.4	11.1 / 22.3	18.2 / 36.7
		16.0	55/45%	3.9 / 7.9	6.2 / 12.4	10.1 / 20.3

Table 4-4 Damage Cost Sensitivity (2-Axle Buses) (33% uptake)

Analysis vehicle	Load Scenario	Rear Group Limit (tonnes)	Predicted Increase in Cost ($M)		
			State Highways	Local Roads	Total
All 2-axle buses – rear axle set	General Mass Limits	8.2	-	-	-
	Increase to 8.8 tonnes	8.8	4.2 / 8.4	7.0 / 13.5	11.2 / 21.9

The proportion of these weaker pavements after doubling their length is still relatively low at 3% on the state highway network and 10% on the local authority network. It is also acknowledged that not all of the weaker pavements will be subjected to the higher loadings.

4.4 Specific Route Analysis

The analysis tool has the flexibility to estimate the cost impact by specifying the remaining life for a specific route or known expected distance to be travelled or specific vehicle configuration.

For a specific route analysis, it is recommended that a thorough understanding of the pavement condition is understood prior to completing this assessment.

5. Summary

The analysis shows that a rise in pavement wear can be expected across the national road network under the proposed increased axle group loads for 2 and 3-axle buses.

The data shows a current bus fleet of approximately 9,000 vehicles. They travel approximately 15% of the total VKT for HCVs with a gross vehicle mass of greater > 9 tonnes as these are the vehicles doing the damage to the roads.

The predicted costs are presented for three different scenarios in potential uptake of the increased mass limits i.e. a quarter, a third and half of the total bus fleet, which represents 3.6%, 4.7% and 7.2% of the total travelled distance for each of the scenario s respectively. The calculations used to estimate the increase in pavement wear are based on the vehicles being operated at their permitted maximum masses, and as such, will produce an upper bound cost as not all HVKT are at the maximum limits.

The increase in expenditure for the state highway network is funded exclusively from the NLTP whilst the NLTP funds approximately 50% of the local road expenditure and the local authorities fund the balance via their rating base. The impact on the local roads has a lower degree of confidence due to the uncertainty and assumptions in the knowledge base with respect to the condition of the local roads.

The results of the study are summarised in Table 5-1 and Table 5-2.

Table 5-1 National State Highways – Summary of Predicted Damage Cost Increase (3-Axle Buses)

Analysis vehicle	Load Scenario	Rear Group Limit (tonnes)	Rear Group Load Share Split	Predicted Increase in Cost ($M)		
				State Highways	Local Roads	Total
All 3-axle buses	General Mass Limits	13.6	60/40%	-	-	-
		14.5	55/45%	0.2 0.3 0.4	0.5 0.6 0.8	0.7 (25%) 0.9 (33%) 1.2 (50%)
All 3-axle urban and rural buses including double deck buses (66 seaters)	As per VDAM 2015 Schedule 2, Part C	16.0	60/40%	5.7 7.1 9.9	8.9 11.1 15.5	14.6 18.2 25.4
		16.0	55/45%	3.1 3.9 5.4	5.0 6.2 8.7	8.1 10.1 14.1

Table 5-2 All Local Roads – Summary of Predicted Damage Cost Increase (2-Axle Buses)

Analysis vehicle	Load Scenario	Rear Group Limit (tonnes)	Predicted Increase in Cost ($M)		
			State Highways	Local Roads	Total
All 2-axle buses – rear axle set	General Mass Limits	8.2	-	-	-
	Increase to 8.8 tonnes	8.8	3.4 4.2 5.9	5.6 7.0 9.8	9.0 (25%) 11.2 (33%) 15.7 (50%)

The biggest unknown is the length of local roads in the weak and medium strength categories that will be subjected to the increase in loading – the impact is known but the total scale/extent is unknown. A sensitivity analysis showed that the damage cost doubles with doubling of the proportion of weaker pavements on the network.

Approximately 4% of the length of the Wellington City (WCC) network falls within the weak pavement category according to the classification system used in this analysis. On the WCC network the bus routes are well defined however on the majority of the national state highway and local road networks we do not know exactly which routes are being used by buses. More detailed study is required to define these routes in order to refine the cost impact of increased axle loads on buses.

The proportion of these weaker pavements after doubling their length is still relatively low at 3% on the state highway network and 10% on the local authority network. It is also acknowledged that not all of the weaker pavements will be subjected to the higher loadings.

6. References

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Ministry of Transport (2010). Land Transport Rule – Vehicle Dimensions and Mass Amendment 2010, Rule 41001/5. Wellington, New Zealand.

Ministry of Transport (2010). Land Transport Rule – Vehicle Dimensions and Mass Amendment 2015, Rule 41001/5. Wellington, New Zealand.

http://www.transport.govt.nz/ourwork/tmif/transport-volume/tv001 & 2

APPENDIX A: Study methodology and assumptions

Introduction

This section outlines the methodology used to assess the additional pavement wear related costs that could be attributed to an increase in the allowable axle group loads.

The model has two parts; the first part calculates a pavement wear cost per kilometre travelled for a standard axle load using network data and actual costs. The second part is set up to use the rut prediction pavement damage model to compare the pavement wear caused by a vehicle loaded to the current General Mass Limits and loaded to the proposed HPMV limits. The outputs from the two parts are then combined to determine the increase in pavement wear costs resulting from the proposed increases in axle mass limits.

The method combines the HKVT, the distribution of calculated remaining pavement life, the measured axle load spectrum and the total road maintenance cost to determine a calibrated pavement wear cost per standard axle load per kilometre travelled.

The data used in this analysis is sourced from the NZ Transport Agency, Ministry of Transport and research conducted at the Transport Agency's accelerated pavement testing facility.

The methodology followed is outlined below.

A1. Part 1 – Calibrated cost/wear model

A1.1 Vehicle and Heavy Vehicle Kilometres Travelled (VKT and HVKT)

The VKT figure is obtained from the MOT and is derived from CoF odometer readings. The MoT also publishes HVKT figures that are derived from the CoF data, however the MoT defines a heavy vehicle as a vehicle with a gross mass greater than 3.5 tonnes. In terms of this study, the vehicles of interest are those that are loaded close to the legal limits for the specific axle groups, i.e. 14.2 tonnes for a two axle buses (6.0 single steer axle + 8.2 t dual wheel rear axle) and 20.5 tonnes for a three axle bus (6.0 single steer axle + 14.5 t dual wheel rear axle).

The HVKT total used in this model was derived from the amount of road user charges purchased. It is assumed that RUCs are consumed within a relatively short timeframe after purchase. The RUC data was filtered to exclude:

- 2 axles vehicles with a gross mass of less than 9 tonnes;
- 3 axle vehicles with a gross mass of less than18 tonnes (these vehicles are 5% of the total no. of 3 axle vehicles);
- All trailers/unpowered vehicles

Table A1-0-1 Vehicle kilometers travelled split

Vehicle type	VKT (million km)	HVKT(million km)
All vehicles[1]	41,600	
Heavy vehicles[2]		2,105
Buses[3] (included in above total)		300

[1] http://www.transport.govt.nz/ourwork/tmif/transport-volume/tv001/

[2] Data supplied by MoT

[3] http://www.transport.govt.nz/ourwork/tmif/transport-volume/tv002/

A1.2 SH/LR HVKT split

The MoT has analysed the traffic count and classification data from the state highway traffic counter network and have derived an estimated HVKT figure for the state highways. Their calculations state that 72% of the HVKT occurs on the state highway network and the balance of 28% occurs on the local road network. For this study the local road network was analysed collectively as it was not possible to calculate the VKT for each individual local road network. This analysis also assumed 5% of the HVKT is from the individual 2 or 3 axle buses assessed in this report.

A1.3 Remaining Pavement Life

For this project, the remaining pavement life was initially determined by the pavement structural number (SNP) for each treatment length. The SNP was originally developed in the USA as a means to determine the required pavement thickness for a new pavement for a given loading and over time has been adapted to assign a strength/capacity value to existing pavements.

For existing pavements the SNP is calculated as a function of the pavement deflection as measured by a Falling Weight Deflectometer. This approach has many short comings as no consideration of material quality or layer thicknesses are used in the calculation. The main benefit of using SNP for existing pavements is that it can be used to assess the overall network condition if the required deflection data is available. In this situation it should be used as a comparative indicator rather than an absolute value. The SNP values for the state highway network have been calculated for each treatment length from deflection data and are stored in the RAMM database. The SNP value for each treatment length was allocated into five ranges, ranging from weak to strong. The pavements sections with the lowest SNP values were assumed to have a low remaining life whilst the pavements with the higher SNP values were assumed to have a significant remaining life.

During the project the project team was authorised to use the data from the *Regional Precedent Performance Study of Pavements* project that has been recently completed by Geosolve Ltd. This data provided a breakdown of estimated remaining pavement life in terms of equivalent standard axles (ESA) for each treatment length and is based on a rigorous analysis of historical deflection measurements.

This data was available for the state highway network and some local authority networks. Similar to the initial SNP approach, the remaining life data was split into six categories based on the estimated remaining life in terms of ESA, with the length of pavement reported for each category. This study assumed the pavement strength distribution on the Southland District Council road network for all roads outside of the state highway network.

Table A1-0-2 State Highway Pavement Classes

Pavement Class	Remaining Life (Million ESA (MESA), 50%ile value)	Network Length (%)
1	0.015	0.3
2	0.128	0.4
3	0.352	0.9
4	3.512	27.6
5	10.295	19.6
6	64.312	51.3

Table A1-0-3 Local Road Pavement Classes (Southland DC Network)

Pavement Class	Remaining Life (Million ESA (MESA), 50%ile value)	Network Length (%)
1	0.016	0.4
2	0.131	1.3
3	0.350	3.4
4	2.984	59.9
5	10.110	17.9
6	36.038	17.2

A1.4 Average ESA/vehicle

The average ESA per vehicle was calculated based on the detailed axle weight data and vehicle types recorded at the six WIM sites around New Zealand. The individual axle/bin and vehicle type data was combined on a weighted average basis dependant on the count data from each WIM site. This gave a single spectrum for axle loads and vehicle type counts.

For each axle group (single, tandem, tridem, quad), the ESA for each axle mass bin (10 kN increments) was calculated and a weighted average ESA value was obtained for each axle group.

This information was then used to determine the ESA value for each recorded vehicle type, i.e. the ESA for a 3 axle truck and 4 axle trailer combination would be the sum of the weighted ESA values for a single axle and 3 tandem axle groups (1x for the rear vehicle axle group and 2x for the front and rear axle groups in the trailer).

The ESA values for each vehicle type were then used to calculate a weighted average ESA value per HCV. This value was calculated to be 1.67 ESA/HCV.

A1.5 Pavement Rehabilitation Cost/ESA/km

The pavement cost related solely to pavement wear was determined by dividing the estimated cost to rehabilitate a kilometre of carriageway by the remaining life for each pavement class. This gave a cost per ESA per kilometre of pavement. The rehabilitation cost was assumed to be $200,000/km. This was based on a nominal 100 mm thick overlay and chipseal surface as this was assumed to be the minimum amount of work required to add structural capacity and restore the ride quality. No improvements to geometry or drainage have been included in the cost estimate. This cost relates to a rural highway that is 10 metres wide.

The cost per kilometre for the lowest pavement class is the highest as this class has the smallest number of remaining ESA over which to spread the rehabilitation cost, conversely the highest pavement class has the lowest cost/ESA as this class has the highest remaining life.

Although the $200,000/km maybe argued as too low or too high the actual value in the analysis does not matter as a multiplier adjustment factor was applied to the lives for each pavement class such that when the cost per ESA per km was multiplied by the total number of ESA on the road network the total damage cost was equal to the actual spend on the state highway or local roads associated to heavy vehicle damage. Using the $200,000 per km resulted in the Geosolve 50th percentile predicted lives for the 6 pavement classes to be multiplied by a factor of 1.7 for the State Highways.

A1.6 Pavement Wear Cost/HCV

The average wear cost per HCV was determined by multiplying the cost of wear per ESA/km and the ESA/HCV. The cost of wear per ESA/km was calculated by dividing the sum of the product of the cost/ESA/km and network length for each pavement class, by the total network length. As discussed above the average wear cost is calibrated to ensure when multiplied by the HVKT and the ESA per HVKT the total spend matches the actual spend on the network for heavy vehicle road damage.

A1.7 Actual pavement related costs

The MoT has developed a cost allocation model (CAM) in order to allocate the total NLTP expenditure across various areas of expenditure. This model is a reactive cost allocation model in that the allocations are balanced against the actual/budgeted expenditure. The areas of interest for this project are the maintenance and operation and renewal costs. The M&O costs includes reactive carriageway works, corridor maintenance costs (signs, vegetation control etc.) whilst the renewal costs cover rehabilitation and reseal work. It is acknowledged that these amounts include costs that are not related to pavement wear however it was accepted that the pavement only related costs do not exist in an easily obtainable or consistent form.

One of the cost allocation components in the CAM is pavement wear; this is assumed to cover the cost of pavement wear caused by HCVs. It is understood that the costs allocated to the pavement wear component are linked to the distance and weight of the RUCs that are purchased.

The CAM allocates 19.5% of the M&O and renewal costs to the pavement wear component for state highways and 23% for the local roads. It is these values that are used for the calibration of the pavement wear allocations developed in this study. The figures used for the local roads are the total costs. The local authorities receive a subsidy (Financial Assistance rate (FAR)) from the NLTP for eligible works. The FAR for the dataset used in this study was 56%, i.e. the local authorities' share of the cost was 44% of the total costs.

A1.8 Calibration of model output

The cost/HCV/km calculated above (section 1.6) was compared with the assumed pavement wear costs for M&O and renewal work from the CAM. A calibration factor was introduced into the pavement wear model so that the assumed cost of pavement wear matched the allocated expenditure for pavement wear in the CAM.

A1.9 Final output

The final output for this model is a cost per ESA per kilometre travelled as applied to the entire network.

A2. Part 2 – Estimated costs for increased axle loadings

This model uses the $/ESA/km value developed in Part 1 to work out the increase in pavement wear cost for a specified vehicle configuration and axle loadings.

For this part, it is assumed that the HVKT figure is with the vehicles loaded to their GML or HPMV limits. This will produce an upper bound estimate of the costs.

A2.1 Cost for a specific vehicle loaded to GML

The ESA value for a specific bus was calculated using the fourth power law and assumed that the bus was loaded to the maximum permitted by the General Mass Limits. The calculated ESA value was then multiplied by the cost per ESA per kilometre for each pavement class. The pavement wear on the different pavement classes was factored in by calculating a weighted average of the cost per bus pass per kilometre.

In addition to using the fourth power law for determining pavement wear, a model utilising material test data and pavement rutting information from the Transport Agency Accelerated Pavement Testing facility (CAPTIF) was used to determine the rate of pavement wear for different pavement and loading scenarios. The output from this model was a variable load damage exponent instead of the historical exponent value of 4. It was found that this model calculated a higher rate of pavement wear than the fourth power approach. In particular, the rate of wear was greater for the weaker pavements. The damage exponents range from 1 (strong pavements) to 9 (weak pavements).

The results presented in this report are based on the latter approach in which a variable load damage exponent was used.

A2.2 Cost for a specific vehicle loaded to proposed axle limits

The ESA value for the specified bus loaded to the proposed axle limits was calculated using the variable damage exponent and the weighted cost per bus pass per kilometre was determined as above.

A2.3 Fleet mix and efficiency gains

In order to determine the impact of a specific change to the axle limits for a 2 or 3 axle buses, an assessment of the percentage or distance of the total HVKT for the specific bus is made. This allows the impact of the increased axle limits for the specific vehicle to be assessed.

In addition it is assumed that the passenger task remains constant, i.e. an increase in the mass limit for the specific bus configuration will result in fewer trips. For each type of bus assessed, an estimate of the tare weight was made; this allows the net freight mass to be determined for the general mass limits and increased axle cases. It has been assumed that the bus tare weight remains constant for the different scenarios. The efficiency gain is based on the difference in the net weights for the various cases.

Once the road wear cost has been calculated for each of the GML and proposed limits, the cost/bus/km is multiplied by the distance travelled to give an annual cost for the bus. The efficiency gain is incorporated by a reduction in the distance travelled for each bus configuration. The increase in road wear cost is the difference between the GML case and the proposed limits.

A3. National Network Analysis

A whole of country analysis was conducted for the state highway and local road networks. This gives a cost impact for the Transport Agency and a total cost estimate for the local authorities. The datasets used for the state highway network are considered to be reliable, given the type and coverage of traffic data across the state highway network; this implies a higher degree of confidence in the cost implications for the Transport Agency. The quality and extent of pavement condition and traffic data for the local road networks varies between local authorities and as such, the metrics developed for the state highway data have been used to fill information/data gaps in the local road datasets.

A4. Specific Route Analysis

The analysis tool has the flexibility to estimate the cost impact by specifying the remaining life for a specific route or known expected distance to be travelled or specific vehicle configuration.

For a specific route analysis, it is recommended that a thorough understanding of the pavement condition is understood prior to completing this assessment.

A5. Results

The results of the study are summarised in the tables following for both the state highways and the local road components of the road network.

NATIONAL STATE HIGHWAYS: 25% UPTAKE

							Extremely weak	Very weak	Weak	Average	Strong	Very strong						
						Pavement Class												
						Damage exponent	9.0	5.6	3.5	1.9	1.1	1.1						
						Expected rem. life MESA	0.025	0.217	0.596	5.951	17.445	108.977						
						Length (km)	24	32	69	2229	1579	4142						
						Network length	0%	0%	1%	28%	20%	51%						
Vehicle	Current or New[1]	GVM (kg)	Steer Axle (kg)	Rear Axle Group (kg)	Rear Axle Split	Eff.[2]	Cost per km per vehicle pass ($)						% of vehicle fleet	km of travel per year (million km)	Predicted Damage cost per year ($M)	Difference in Damage cost cf current load per year ($M)	Difference in Damage cost cf current load per vehicle per km ($)	Increase in cost
3-Axle Bus	Current	19600	6000	13600	60/40	-	25.68	2.69	0.97	0.10	0.03	0.01	4	60.61	7.92	-	-	-
3-Axle Bus	New	22000	6000	16000	60/40	81%	68.85	5.04	1.42	0.12	0.04	0.01	4	48.94	13.59	5.68	0.12	72%
3-Axle Bus	Current	20500	6000	14500	55/45	-	26.54	2.82	1.00	0.10	0.03	0.01	4	60.61	8.16	-	-	-
3-Axle Bus	New	22000	6000	16000	55/45	88%	48.34	4.19	1.29	0.11	0.04	0.01	4	53.32	11.27	3.11	0.07	38%
2-Axle Bus	Current	14200	6000	8200	100/0	-	23.73	2.25	0.74	0.07	0.02	0.00	4	60.61	6.71	-	-	-
2-Axle Bus	New	14800	6000	8800	100/0	94%	42.81	3.43	0.99	0.08	0.03	0.00	4	56.90	10.11	3.40	0.06	51%

1. Current vehicle complies with the 2010 Gross Mass Limits
2. Reduction in distance travelled due to increase in payload

NATIONAL STATE HIGHWAYS: 33% UPTAKE

							Extremely weak	Very weak	Weak	Average	Strong	Very strong						
						Pavement Class												
						Damage exponent	9.0	5.6	3.5	1.9	1.1	1.1						
						Expected rem. life MESA	0.025	0.217	0.596	5.951	17.445	108.977						
						Length (km)	24	32	69	2229	1579	4142						
						Network length	0%	0%	1%	28%	20%	51%						
Vehicle	Current or New[1]	GVM (kg)	Steer Axle (kg)	Rear Axle Group (kg)	Rear Axle Split	Eff.[2]	Cost per km per vehicle pass ($)						% of vehicle fleet	km of travel per year (million km)	Predicted Damage cost per year ($M)	Difference in Damage cost cf current load per year ($M)	Difference in Damage cost cf current load per vehicle per km ($)	Increase in cost
3-Axle Bus	Current	19600	6000	13600	60/40	-	25.68	2.69	0.97	0.10	0.03	0.01	5	75.77	9.90	-	-	-
3-Axle Bus	New	22000	6000	16000	60/40	81%	68.85	5.04	1.42	0.12	0.04	0.01	5	61.17	16.99	7.09	0.12	72%
3-Axle Bus	Current	20500	6000	14500	55/45	-	26.54	2.82	1.00	0.10	0.03	0.01	5	75.77	10.20	-	-	-
3-Axle Bus	New	22000	6000	16000	55/45	88%	48.34	4.19	1.29	0.11	0.04	0.01	5	66.64	14.08	3.88	0.07	38%
2-Axle Bus	Current	14200	6000	8200	100/0	-	23.73	2.25	0.74	0.07	0.02	0.00	5	75.77	8.39	-	-	-
2-Axle Bus	New	14800	6000	8800	100/0	94%	42.81	3.43	0.99	0.08	0.03	0.00	5	71.13	12.63	4.24	0.06	51%

1. Current vehicle complies with the 2010 Gross Mass Limits
2. Reduction in distance travelled due to increase in payload

NATIONAL STATE HIGHWAYS: 50% UPTAKE

							Extremely weak	Very weak	Weak	Average	Strong	Very strong						
						Pavement Class												
						Damage exponent	9.0	5.6	3.5	1.9	1.1	1.1						
						Expected rem. life MESA	0.025	0.217	0.596	5.951	17.445	108.977						
						Length (km)	24	32	69	2229	1579	4142						
						Network length	0%	0%	1%	28%	20%	51%						
Vehicle	Current or New[1]	GVM (kg)	Steer Axle (kg)	Rear Axle Group (kg)	Rear Axle Split	Eff.[2]	Cost per km per vehicle pass ($)						% of vehicle fleet	km of travel per year (million km)	Predicted Damage cost per year ($M)	Difference in Damage cost cf current load per year ($M)	Difference in Damage cost cf current load per vehicle per km ($)	Increase in cost
3-Axle Bus	Current	19600	6000	13600	60/40	-	25.68	2.69	0.97	0.10	0.03	0.01	7	106.07	13.86	-	-	-
3-Axle Bus	New	22000	6000	16000	60/40	81%	68.85	5.04	1.42	0.12	0.04	0.01	7	85.64	23.79	9.93	0.12	72%
3-Axle Bus	Current	20500	6000	14500	55/45	-	26.54	2.82	1.00	0.10	0.03	0.01	7	106.07	14.28	-	-	-
3-Axle Bus	New	22000	6000	16000	55/45	88%	48.34	4.19	1.29	0.11	0.04	0.01	7	93.30	19.72	5.44	0.07	38%
2-Axle Bus	Current	14200	6000	8200	100/0	-	23.73	2.25	0.74	0.07	0.02	0.00	7	106.07	11.74	-	-	-
2-Axle Bus	New	14800	6000	8800	100/0	94%	42.81	3.43	0.99	0.08	0.03	0.00	7	99.58	17.69	5.94	0.06	51%

1. Current vehicle complies with the 2010 Gross Mass Limits
2. Reduction in distance travelled due to increase in payload

ALL LOCAL ROADS: 25% UPTAKE

Vehicle	Current or New[1]	GVM (kg)	Steer Axle (kg)	Rear Axle Group (kg)	Rear Axle Split	Eff.[2]	Extremely weak	Very weak	Weak	Average	Strong	Very strong	% of vehicle fleet	km of travel per year (million km)	Predicted Damage cost per year ($M)	Difference in Damage cost cf current load per year ($M)	Difference in Damage cost cf current load per vehicle per km ($)	Increase in cost
						Pavement Class	Extremely weak	Very weak	Weak	Average	Strong	Very strong						
						Damage exponent	9.0	5.6	3.5	1.9	1.1	1.1						
						Expected rem. life MESA	0.025	0.217	0.596	5.951	17.445	108.977						
						Length (km)	366	1,079	2,803	49,862	14,888	14,279						
						Network length	0%	1%	3%	60%	18%	17%						
							Cost per km per vehicle pass ($)											
3-Axle Bus	Current	19600	6000	13600	60/40	-	62.54	6.65	2.45	0.29	0.09	0.02	4	23.57	15.03	-	-	-
3-Axle Bus	New	22000	6000	16000	60/40	81%	167.67	12.45	3.60	0.36	0.10	0.03	4	19.03	23.90	8.87	0.50	59%
3-Axle Bus	Current	20500	6000	14500	55/45	-	64.62	6.96	2.54	0.30	0.09	0.02	4	23.57	15.50	-	-	-
3-Axle Bus	New	22000	6000	16000	55/45	88%	117.73	10.35	3.26	0.34	0.09	0.03	4	20.73	20.47	4.97	0.29	32%
2-Axle Bus	Current	14200	6000	8200	100/0	-	57.79	5.57	1.88	0.21	0.06	0.02	4	23.57	12.45	-	-	-
2-Axle Bus	New	14800	6000	8800	100/0	94%	104.25	8.48	2.50	0.25	0.07	0.02	4	22.13	18.03	5.58	0.27	45%

1. Current vehicle complies with the 2010 Gross Mass Limits
2. Reduction in distance travelled due to increase in payload

ALL LOCAL ROADS: 33% UPTAKE

Vehicle	Current or New[1]	GVM (kg)	Steer Axle (kg)	Rear Axle Group (kg)	Rear Axle Split	Eff.[2]	Extremely weak	Very weak	Weak	Average	Strong	Very strong	% of vehicle fleet	km of travel per year (million km)	Predicted Damage cost per year ($M)	Difference in Damage cost cf current load per year ($M)	Difference in Damage cost cf current load per vehicle per km ($)	Increase in cost
						Pavement Class	Extremely weak	Very weak	Weak	Average	Strong	Very strong						
						Damage exponent	9.0	5.6	3.5	1.9	1.1	1.1						
						Expected rem. life MESA	0.025	0.217	0.596	5.951	17.445	108.977						
						Length (km)	366	1,079	2,803	49,862	14,888	14,279						
						Network length	0%	1%	3%	60%	18%	17%						
							Cost per km per vehicle pass ($)											
3-Axle Bus	Current	19600	6000	13600	60/40	-	62.54	6.65	2.45	0.29	0.09	0.02	5	29.46	18.78	-	-	-
3-Axle Bus	New	22000	6000	16000	60/40	81%	167.67	12.45	3.60	0.36	0.10	0.03	5	23.79	29.87	11.09	0.50	59%
3-Axle Bus	Current	20500	6000	14500	55/45	-	64.62	6.96	2.54	0.30	0.09	0.02	5	29.46	19.38	-	-	-
3-Axle Bus	New	22000	6000	16000	55/45	88%	117.73	10.35	3.26	0.34	0.09	0.03	5	25.92	25.59	6.21	0.29	32%
2-Axle Bus	Current	14200	6000	8200	100/0	-	57.79	5.57	1.88	0.21	0.06	0.02	5	29.46	15.56	-	-	-
2-Axle Bus	New	14800	6000	8800	100/0	94%	104.25	8.48	2.50	0.25	0.07	0.02	5	27.66	22.54	6.98	0.27	45%

1. Current vehicle complies with the 2010 Gross Mass Limits
2. Reduction in distance travelled due to increase in payload

ALL LOCAL ROADS: 50% UPTAKE

Vehicle	Current or New[1]	GVM (kg)	Steer Axle (kg)	Rear Axle Group (kg)	Rear Axle Split	Eff.[2]	Extremely weak	Very weak	Weak	Average	Strong	Very strong	% of vehicle fleet	km of travel per year (million km)	Predicted Damage cost per year ($M)	Difference in Damage cost cf current load per year ($M)	Difference in Damage cost cf current load per vehicle per km ($)	Increase in cost
						Pavement Class	Extremely weak	Very weak	Weak	Average	Strong	Very strong						
						Damage exponent	9.0	5.6	3.5	1.9	1.1	1.1						
						Expected rem. life MESA	0.025	0.217	0.596	5.951	17.445	108.977						
						Length (km)	366	1,079	2,803	49,862	14,888	14,279						
						Network length	0%	1%	3%	60%	18%	17%						
							Cost per km per vehicle pass ($)											
3-Axle Bus	Current	19600	6000	13600	60/40	-	62.54	6.65	2.45	0.29	0.09	0.02	7	41.25	26.30	-	-	-
3-Axle Bus	New	22000	6000	16000	60/40	81%	167.67	12.45	3.60	0.36	0.10	0.03	7	33.30	41.82	15.53	0.50	59%
3-Axle Bus	Current	20500	6000	14500	55/45	-	64.62	6.96	2.54	0.30	0.09	0.02	7	41.25	27.13	-	-	-
3-Axle Bus	New	22000	6000	16000	55/45	88%	117.73	10.35	3.26	0.34	0.09	0.03	7	36.28	35.83	8.69	0.29	32%
2-Axle Bus	Current	14200	6000	8200	100/0	-	57.79	5.57	1.88	0.21	0.06	0.02	7	41.25	21.78	-	-	-
2-Axle Bus	New	14800	6000	8800	100/0	94%	104.25	8.48	2.50	0.25	0.07	0.02	7	38.72	31.56	9.77	0.27	45%

1. Current vehicle complies with the 2010 Gross Mass Limits
2. Reduction in distance travelled due to increase in payload