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Pavement Cost Impact Assessment from Increased Axle Loads on 2 and 3-Axle Buses and Trucks

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Quality Assurance Statement	
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Revision Schedule			
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0	Bruce Steven	Final	18/02/2016
1	Bruce Steven	Updated review on Opus Bus report (Appendix B)	25/02/2016
2	Bruce Steven	Additional loading options included	21/03/2016
3	Bruce Steven	Minor calculation error corrected for 3-axle trucks	21/04/2016

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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 and trucks.

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 and trucks.

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 and trucks. 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 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 and heavy commercial vehicle (HCV) fleet 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 kilometre 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 and truck by recognising that fewer trips will be required to transport the same amount of passengers / freight.

The costs used for the calibration of the pavement wear allocations in this study are the total cost expended on maintenance & operations and renewals on state highways and local roads. The cost for local roads is the total cost including the local authority contribution. 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 Table 0-1 to Table 0-4 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	0.5	0.7 (25%)
				0.3	0.6	0.9 (33%)
				0.4	0.8	1.2 (50%)
All 3-axle urban and rural buses including double deck buses (66-seaters)	As per VDAM 2015 Schedule 2, Part C	14.6	60/40%	3.0	4.9	7.9
				3.8	6.1	9.9
				5.3	8.5	13.8
		16.0	60/40%	5.7	8.9	14.6
				7.1	11.1	18.2
				9.9	15.5	25.4
		16.0	55/45%	3.1	5.0	8.1
				3.9	6.2	10.1
				5.4	8.7	14.1
All 3-axle urban and rural buses - rear axle set	Increase to 16.7 tonnes	16.7	60/40%	7.9	12.2	20.1
				9.9	15.3	25.2
				13.9	21.4	35.3
		16.7	55/45%	4.1	6.5	10.6
				5.2	8.2	13.4
				7.2	11.4	18.6

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	5.6	9.0 (25%)
			4.2	7.0	11.2 (33%)
			5.9	9.8	15.7 (50%)
	Increase to 9.5 tonnes	9.5	6.0	9.6	15.6
			7.5	11.9	19.4
			10.5	16.7	27.2
	Increase to 10.0 tonnes	10.0	9.0	14.1	23.1
			11.2	17.6	28.8
			15.7	24.7	40.4
	Increase to 11.0 tonnes	11.0	19.4	29.7	49.1
			24.3	37.1	61.4
			34.0	52.0	86.0
	Increase to 12.0 tonnes	12.0	39.4	59.2	98.6
			49.3	74.0	123.3
			69.0	103.6	172.6

Table 0-3 Predicted cost increase for 2-Axle Trucks

Analysis vehicle	Load Scenario	Rear Group Limit (tonnes)	Predicted Increase in Cost ($M)		
			State Highways	Local Roads	Total
All 2-axle truck – rear axle set	General Mass Limits	8.2	-	-	-
	Increase to 8.8 tonnes	8.8	9.3	15.4	24.7 (25%)
			11.9	19.5	31.4 (33%)
			17.8	29.3	47.1 (50%)
	Increase to 9.5 tonnes	9.5	16.4	26.3	42.7
			20.9	33.5	54.4
			31.4	50.2	81.6
	Increase to 10.0 tonnes	10.0	24.6	38.8	63.4
			31.4	49.3	80.7
			47.1	74.0	121.1
	Increase to 11.0 tonnes	11.0	53.4	81.7	135.1
			67.9	103.9	171.8
			101.9	155.9	257.8
	Increase to 12.0 tonnes	12.0	108.4	162.8	271.1
			138.0	207.1	345.1
			206.9	310.7	517.6

Table 0-4 Predicted cost increase for 3-Axle Trucks

Analysis vehicle	Load scenario	Rear Group Limit (tonnes)	Predicted Increase in Cost ($M)		
			State Highways	Local Roads	Total
All 3-axle trucks – rear axle set	General Mass Limits	15.0	-	-	-
	Increase to 16.0 tonnes	16.0	6.1	9.7	15.8 (25%)
			7.7	12.4	20.1 (33%)
			11.6	18.5	30.1 (50%)
	Increase to 17.0 tonnes	17.0	8.4	13.4	21.8
			10.7	17.0	27.7
			16.1	25.5	41.6

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 on the bus rear axle group to 14.6, 16.0 and 16.7 tonnes;
- Increased rear axle loads of 8.8, 9.5, 10.0, 11.0 or 12.0 tonnes on all two axle buses with dual-tyred rear axles;
- Similar axle loads on all freight vehicles, i.e. to 8.8, 9.5, 10.0, 11.0 or 12.0 tonnes on the rear axle of 2-axle trucks plus 16 tonnes and 17 tonnes on the tandem dual-tyred rear axle set on 3-axle trucks.

The purpose of this study is to evaluate the cost impact of pavement maintenance from increased axle loads on 2 and 3-axle buses and trucks. 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 2 and 3-axle buses and trucks.

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.

The appendices also include the following:-

- Appendix B - A review of the double deck bus pavement impact assessment by Opus International Consultants Ltd for the Wellington City Council.
- Appendix C - A study on the impact on pavement wear due to changes to single and tandem axle group mass limits on a sample network (HPMV Tranche2 routes), which used a weighted axle spectrum as input into the pavement wear component of the maintenance demand modelling process within dTIMS.

  The results of this analysis showed that impact of increased axle loads did not significantly change the network level load distributions. In addition it was felt that the maintenance cost base data did not have sufficient resolution for this work due to the way in which the data is collected under current practices. Therefore this work was set aside and a route specific dependant analysis was undertaken. The underlying pavement performance model was developed as described in Appendix D.
- Appendix D - A route-specific pavement life prediction tool based on NZTA CAPTIF research into rut depths under a range of tyre loads and tyre pressures from current legal load to the new proposed loads is also included in the appendices.

  The output from this work was used to develop pavement strength related damage effects and is incorporated into the methodology outlined in Appendix A of 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 Ministry of Transport (MoT) cost allocation model (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 vehicles loaded to their GML or increased axle limits. This will produce an upper bound estimate of the costs. Data from the NZTA and MoT show that the HVKT assigned to buses is approximately 15% of the total HVKT figure, and the HVKT assigned to 2 and 3-axle trucks (including truck & trailer units with 7 or less axles) approximately 42% 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 or truck, an assessment of the percentage or distance of the total HVKT for the specific bus or truck 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 heavy vehicle fleet (2 and 3-axle buses and trucks with GVM > 9 tonnes). For the bus fleet this represents 3.6%, 4.7% and 7.2% of the total bus travelled distance respectively, and for trucks 11%, 14% and 21% of the total HCV distance travelled 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/freight task remains constant, i.e. an increase in the mass limit for the specific vehicle configuration will result in fewer trips. For each type of vehicle assessed, an estimate of the tare weight was made; this allows the net passenger/freight mass to be determined for the general mass limits and increased axle load cases. It has been assumed that the vehicle 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) 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 study results are summarised for the state highway road network and the local roads in Table 4-1 and Table 4-2 below. These tables show the expected pavement wear related cost per year for each of the vehicles assessed, and the cost difference for vehicles with increased axle loads and those loaded to the current GML limits. Detailed outputs are presented in Appendix A.

The results are grouped for each vehicle type under consideration (bus or truck) and further grouped by the respective load split on the rear axle of each vehicle. 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 vehicle type takes into account the freight task efficiency and are based on the assumed percentage uptake of each vehicle. 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	20600	6000	14600	91%	68.92	13.66	3.76	0.06	38%
New	22000	6000	16000	81%	61.17	16.99	7.09	0.12	72%
New	22700	6000	16700	76%	57.92	19.79	9.90	0.16	100%
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%
New	22700	6000	16700	83%	63.10	15.38	5.18	0.09	51%
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%
New	15500	6000	9500	88%	66.39	15.86	7.47	0.11	89%
New	16000	6000	10000	84%	63.37	19.59	11.20	0.17	134%
New	17000	6000	11000	77%	58.09	32.64	24.25	0.35	289%
New	18000	6000	12000	71%	53.62	57.66	49.27	0.68	587%
2-Axle Truck									
Current	14200	6000	8200	-	212.14	23.49	-	-	-
New	14800	6000	8800	94%	199.15	35.37	11.88	0.06	51%
New	15500	6000	9500	88%	185.88	44.40	20.91	0.11	89%
New	16000	6000	10000	84%	177.43	54.86	31.37	0.17	134%
New	17000	6000	11000	77%	162.64	91.39	67.90	0.35	289%
New	18000	6000	12000	71%	150.13	161.44	137.95	0.68	587%
3-Axle Truck									
Current	21000	6000	15000	-	212.14	28.63	-	-	-
New	22000	6000	16000	94%	199.66	36.37	7.74	0.04	27%
New	23000	6000	17000	89%	188.57	39.35	10.72	0.07	37%

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

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	20600	6000	14600	91%	26.80	24.88	6.10	0.26	32%
New	22000	6000	16000	81%	23.79	29.87	11.09	0.50	59%
New	22700	6000	16700	76%	22.52	34.05	15.27	0.67	81%
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%
New	22700	6000	16700	83%	24.54	27.53	8.15	0.39	42%
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%
New	15500	6000	9500	88%	25.82	27.51	11.95	0.47	77%
New	16000	6000	10000	84%	24.64	33.18	17.62	0.68	113%
New	17000	6000	11000	77%	22.59	52.67	37.11	1.38	239%
New	18000	6000	12000	71%	20.85	89.54	73.98	2.67	475%
2-Axle Truck									
Current	14200	6000	8200	-	82.50	43.57	-	-	-
New	14800	6000	8800	94%	77.45	63.11	19.54	0.27	45%
New	15500	6000	9500	88%	72.29	77.02	33.45	0.47	77%
New	16000	6000	10000	84%	69.00	92.89	49.32	0.68	113%
New	17000	6000	11000	77%	63.25	147.49	103.92	1.38	239%
New	17000	6000	12000	71%	63.25	250.71	207.14	2.67	475%
3-Axle Truck									
Current	21000	6000	15000	-	82.50	54.70	-	-	-
New	22000	6000	16000	94%	77.65	67.06	12.36	0.19	23%
New	23000	6000	17000	89%	73.33	71.71	17.02	0.28	31%

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 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 to Table 4-6 and show the predicted increase in damage cost per vehicle 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 and HCV fleet to the proposed increased axle loads listed below.

The analysis shows that the damage cost doubles with doubling of the length of weaker pavements on the network. 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.

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	14.6	60/40%	3.8 / 7.5	6.1 / 12.0	9.9 / 19.5
		16.0		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
All 3-axle urban and rural buses - rear axle set	Increase to 16.7 tonnes	16.7	60/40%	9.9 / 20.2	15.3 / 30.7	25.2 / 50.9
		16.7	55/45%	5.2 / 10.6	8.2 / 16.4	13.4 / 27.0

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
	Increase to 9.5 tonnes	9.5	7.5 / 14.9	11.9 / 23.5	19.4 / 38.4
	Increase to 10.0 tonnes	10.0	11.2 / 22.5	17.6 / 34.8	28.8 / 57.3
	Increase to 11.0 tonnes	11.0	24.3 / 48.9	37.1 / 73.7	61.4 / 122.6
	Increase to 12.0 tonnes	12.0	49.3 / 99.5	74.0 / 147.3	123.2 / 246.8

Table 4-5 Damage Cost Sensitivity (2-Axle Trucks) (33% uptake)

Analysis vehicle	Load Scenario	Rear Group Limit (tonnes)	Predicted Increase in Cost ($M)		
			State Highways	Local Roads	Total
All 2-axle trucks – rear axle set	General Mass Limits	8.2	-	-	-
	Increase to 8.8 tonnes	8.8	11.9 / 23.5	19.5 / 37.9	31.4 / 61.4
	Increase to 9.5 tonnes	9.5	20.9 / 41.8	33.5 / 65.7	54 4 / 107.5
	Increase to 10.0 tonnes	10.0	31.4 / 63.0	49.3 / 97.4	80.7 / 160.4
	Increase to 11.0 tonnes	11.0	67.9 / 136.9	103.9 / 206.4	171.8 / 343.3
	Increase to 12.0 tonnes	12.0	138.0 / 278.5	207.1 / 412.5	345.1 / 691.0

Table 4-6 Damage Cost Sensitivity (3-Axle Trucks) (33% uptake)

Analysis vehicle	Load Scenario	Rear Group Limit (tonnes)	Predicted Increase in Cost ($M)		
			State Highways	Local Roads	Total
All 3-axle trucks – rear axle set	General Mass Limits	15.0	-	-	-
	Increase to 16.0 tonnes	16.0	7.7 / 15.7	12.4 / 24.8	20.1 / 40.5
	Increase to 17.0 tonnes	17.0	10.7 / 21.9	17.0 / 34.3	27.7 / 56.2

If the heavier loads are restricted to the routes with stronger pavements the risk of significant cost increase from an incremental increase in loading on a network basis will be lower as these routes would have been constructed and maintained to sustain a higher number of heavy vehicles.

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 and trucks. 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 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 and HCV fleet 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 results of the study are summarised in Table 5-1 and Table 5-2.

Table 5-1 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	0.5	0.7 (25%)
				0.3	0.6	0.9 (33%)
				0.4	0.8	1.2 (50%)
All 3-axle urban and rural buses including double deck buses (66-seaters)	As per VDAM 2015 Schedule 2, Part C	14.6	60/40%	3.0	4.9	7.9
				3.8	6.1	9.9
				5.3	8.5	13.8
		16.0	60/40%	5.7	8.9	14.6
				7.1	11.1	18.2
				9.9	15.5	25.4
		16.0	55/45%	3.1	5.0	8.1
				3.9	6.2	10.1
				5.4	8.7	14.1
All 3-axle urban and rural buses - rear axle set	Increase to 16.7 tonnes	16.7	60/40%	7.9	12.2	20.1
				9.9	15.3	25.2
				13.9	21.4	35.3
		16.7	55/45%	4.1	6.5	10.6
				5.2	8.2	13.4
				7.2	11.4	18.6

Table 5-2 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	5.6	9.0 (25%)
			4.2	7.0	11.2 (33%)
			5.9	9.8	15.7 (50%)
	Increase to 9.5 tonnes	9.5	6.0	9.6	15.6
			7.5	11.9	19.4
			10.5	16.7	27.2
	Increase to 10.0 tonnes	10.0	9.0	14.1	23.1
			11.2	17.6	28.8
			15.7	24.7	40.4
	Increase to 11.0 tonnes	11.0	19.4	29.7	49.1
			24.3	37.1	61.4
			34.0	52.0	86.0
	Increase to 12.0 tonnes	12.0	39.4	59.2	98.6
			49.3	74.0	123.3
			69.0	103.6	172.6

Table 5-3 Summary of Predicted Damage Cost Increase (2-Axle Trucks)

Analysis vehicle	Load Scenario	Rear Group Limit (tonnes)	Predicted Increase in Cost ($M)		
			State Highways	Local Roads	Total
All 2-axle truck – rear axle set	General Mass Limits	8.2	-	-	-
	Increase to 8.8 tonnes	8.8	9.3	15.4	24.7 (25%)
			11.9	19.5	31.4 (33%)
			17.8	29.3	47.1 (50%)
	Increase to 9.5 tonnes	9.5	16.4	26.3	42.7
			20.9	33.5	54.4
			31.4	50.2	81.6
	Increase to 10.0 tonnes	10.0	24.6	38.8	63.4
			31.4	49.3	80.7
			47.1	74.0	121.1
	Increase to 11.0 tonnes	11.0	53.4	81.7	135.1
			67.9	103.9	171.8
			101.9	155.9	257.8
	Increase to 12.0 tonnes	12.0	108.4	162.8	271.1
			138.0	207.1	345.1
			206.9	310.7	517.6

Table 5-4 Summary of Predicted Damage Cost Increase (3-Axle Trucks)

Analysis vehicle	Load scenario	Rear Group Limit (tonnes)	Predicted Increase in Cost ($M)		
			State Highways	Local Roads	Total
All 3-axle trucks – rear axle set	General Mass Limits	15.0	-	-	-
	Increase to 16.0 tonnes	16.0	6.1	9.7	15.8
			7.7	12.4	20.1
			11.6	18.5	30.1
	Increase to 17.0 tonnes	17.0	8.4	13.4	21.8
			10.7	17.0	27.7
			16.1	25.5	41.6

The costs used for the calibration of the pavement wear allocations in this study are the total cost expended on maintenance & operations and renewals on state highways and local roads. The cost for local roads is the total cost including the local authority contribution. 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 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 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

Arnold, G., Henning, T., Alabaster, F., Greenslade, F., & Fussell, A. C. (In print). The relationship between vehicle axle loadings and pavement wear on local roads. Wellington: NZ Transport Agency.
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.

1. Part 1 – Calibrated Cost/Wear Model

1.1. 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 vehicle (6.0 single steer axle + 8.2 t dual wheel rear axle) and 20.5 tonnes for a three axle vehicle (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 1-1 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/

1.2. 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 assumes that 5% of the HVKT is from the individual 2 or 3-axle buses, and 14% from the 2 and 3-axle trucks assessed in this report.

1.3. 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 1-2 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 1-3 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

1.4. 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 truck 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 truck 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 truck 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 truck axle group and 2x for the front and rear axle groups in the trailer).

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

1.5. 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.

1.6. 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.

1.7. 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 total M&O and renewal expenditure in 2013/14 was $446.7m for state highways and $862.9m for local roads. 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.

1.8. 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.

1.9. Final output

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

2. 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.

2.1. Cost for a specific vehicle loaded to GML

The ESA value for a specific vehicle was calculated using the fourth power law and assumed that the vehicle 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 vehicle 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.

2.2. Cost for a specific vehicle loaded to proposed axle limits

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

2.3. 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 and trucks, an assessment of the percentage or distance of the total HVKT for the specific vehicle 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/freight task remains constant, i.e. an increase in the mass limit for the specific vehicle configuration will result in fewer trips. For each type of vehicle 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 vehicle 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/vehicle/km is multiplied by the distance travelled to give an annual cost for the vehicle. The efficiency gain is incorporated by a reduction in the distance travelled for each vehicle configuration. The increase in road wear cost is the difference between the GML case and the proposed limits.

3. 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.

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. 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

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 ($)	Increase in cost
						Pavement Class	Extremely weak	Very weak	Weak	Average	Strong	Very strong						
						Damage exponent	9.0	5.6	3.5	1.9	1.1	1.1						
						Expected rem. life MESA	0.025	0.217	0.596	5.951	17.445	108.977						
						Length (km)	24	32	69	2229	1579	4142						
						Network length	0%	0%	1%	28%	20%	51%						
							Cost per km per vehicle pass ($)											
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	20600	6000	14600	60/40	91%	44.81	3.90	1.22	0.11	0.04	0.01	4	55.13	10.92	3.01	0.06	38%
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	New	22700	6000	16700	60/40	76%	88.80	5.79	1.53	0.12	0.04	0.01	4	46.33	15.84	7.92	0.16	100%
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%
3-Axle Bus	New	22700	6000	16700	55/45	83%	58.01	4.68	1.38	0.12	0.04	0.01	4	50.48	12.30	4.14	0.09	51%
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%
2-Axle Bus	New	15500	6000	9500	100/0	88%	61.42	4.28	1.13	0.09	0.03	0.00	4	53.11	12.69	5.97	0.11	89%
2-Axle Bus	New	16000	6000	10000	100/0	84%	83.41	5.10	1.25	0.09	0.03	0.00	4	50.69	15.67	8.96	0.17	134%
2-Axle Bus	New	17000	6000	11000	100/0	77%	164.45	7.41	1.54	0.10	0.03	0.00	4	46.47	26.11	19.40	0.35	289%
2-Axle Bus	New	18000	6000	12000	100/0	71%	332.36	10.94	1.90	0.12	0.03	0.00	4	42.90	46.13	39.42	0.68	587%
2-Axle Truck	Current	14200	6000	8200	100/0	-	23.73	2.25	0.74	0.07	0.02	0.00	11	166.68	18.45	-	-	-
2-Axle Truck	New	14800	6000	8800	100/0	94%	42.81	3.43	0.99	0.08	0.03	0.00	11	156.48	27.79	9.34	0.06	51%
2-Axle Truck	New	15500	6000	9500	100/0	88%	61.42	4.28	1.13	0.09	0.03	0.00	11	146.05	34.88	16.43	0.11	89%
2-Axle Truck	New	16000	6000	10000	100/0	84%	83.41	5.10	1.25	0.09	0.03	0.00	11	139.41	43.10	24.65	0.17	134%
2-Axle Truck	New	17000	6000	11000	100/0	77%	164.45	7.41	1.54	0.10	0.03	0.00	11	127.79	71.81	53.35	0.35	289%
2-Axle Truck	New	18000	6000	12000	100/0	71%	332.36	10.94	1.90	0.12	0.03	0.00	11	117.96	126.85	108.39	0.68	587%
3-Axle Truck	Current	21000	6000	15000	50/50	-	26.11	2.85	1.03	0.10	0.04	0.01	11	166.68	22.50	-	-	-
3-Axle Truck	New	22000	6000	16000	50/50	94%	39.91	3.70	1.19	0.11	0.04	0.01	11	156.88	28.58	6.08	0.04	27%
3-Axle Truck	New	23000	6000	17000	50/50	89%	47.43	4.18	1.29	0.11	0.04	0.01	11	148.16	30.92	8.42	0.07	37%

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

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 ($)	Increase in cost
						Pavement Class	Extremely weak	Very weak	Weak	Average	Strong	Very strong						
						Damage exponent	9.0	5.6	3.5	1.9	1.1	1.1						
						Expected rem. life MESA	0.025	0.217	0.596	5.951	17.445	108.977						
						Length (km)	24	32	69	2229	1579	4142						
						Network length	0%	0%	1%	28%	20%	51%						
							Cost per km per vehicle pass ($)											
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	20600	6000	14600	60/40	91%	44.81	3.90	1.22	0.11	0.04	0.01	5	68.92	13.66	3.76	0.06	38%
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	New	22700	6000	16700	60/40	76%	88.80	5.79	1.53	0.12	0.04	0.01	5	57.92	19.79	9.90	0.16	100%
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%
3-Axle Bus	New	22700	6000	16700	55/45	83%	58.01	4.68	1.38	0.12	0.04	0.01	5	63.10	15.38	5.18	0.09	51%
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%
2-Axle Bus	New	15500	6000	9500	100/0	88%	61.42	4.28	1.13	0.09	0.03	0.00	5	66.39	15.86	7.47	0.11	89%
2-Axle Bus	New	16000	6000	10000	100/0	84%	83.41	5.10	1.25	0.09	0.03	0.00	5	63.37	19.59	11.20	0.17	134%
2-Axle Bus	New	17000	6000	11000	100/0	77%	164.45	7.41	1.54	0.10	0.03	0.00	5	58.09	32.64	24.25	0.35	289%
2-Axle Bus	New	18000	6000	12000	100/0	71%	332.36	10.94	1.90	0.12	0.03	0.00	5	53.62	57.66	49.27	0.68	587%
2-Axle Truck	Current	14200	6000	8200	100/0	-	23.73	2.25	0.74	0.07	0.02	0.00	14	212.14	23.49	-	-	-
2-Axle Truck	New	14800	6000	8800	100/0	94%	42.81	3.43	0.99	0.08	0.03	0.00	14	199.15	35.37	11.88	0.06	51%
2-Axle Truck	New	15500	6000	9500	100/0	88%	61.42	4.28	1.13	0.09	0.03	0.00	14	185.88	44.40	20.91	0.11	89%
2-Axle Truck	New	16000	6000	10000	100/0	84%	83.41	5.10	1.25	0.09	0.03	0.00	14	177.43	54.86	31.37	0.17	134%
2-Axle Truck	New	17000	6000	11000	100/0	77%	164.45	7.41	1.54	0.10	0.03	0.00	14	162.64	91.39	67.90	0.35	289%
2-Axle Truck	New	18000	6000	12000	100/0	71%	332.36	10.94	1.90	0.12	0.03	0.00	14	150.13	161.44	137.95	0.68	587%
3-Axle Truck	Current	21000	6000	15000	50/50	-	26.11	2.85	1.03	0.10	0.04	0.01	14	212.14	28.63	-	-	-
3-Axle Truck	New	22000	6000	16000	50/50	94%	39.91	3.70	1.19	0.11	0.04	0.01	14	199.66	36.37	7.74	0.04	27%
3-Axle Truck	New	23000	6000	17000	50/50	89%	47.43	4.18	1.29	0.11	0.04	0.01	14	188.57	39.35	10.72	0.07	37%

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

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 ($)	Increase in cost
						Pavement Class	Extremely weak	Very weak	Weak	Average	Strong	Very strong						
						Damage exponent	9.0	5.6	3.5	1.9	1.1	1.1						
						Expected rem. life MESA	0.025	0.217	0.596	5.951	17.445	108.977						
						Length (km)	24	32	69	2229	1579	4142						
						Network length	0%	0%	1%	28%	20%	51%						
							Cost per km per vehicle pass ($)											
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	20600	6000	14600	60/40	91%	44.81	3.90	1.22	0.11	0.04	0.01	7	96.48	19.12	5.26	0.06	38%
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	New	22700	6000	16700	60/40	76%	88.80	5.79	1.53	0.12	0.04	0.01	7	81.09	27.71	13.86	0.16	100%
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%
3-Axle Bus	New	22700	6000	16700	55/45	83%	58.01	4.68	1.38	0.12	0.04	0.01	7	88.34	21.53	7.25	0.09	51%
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%
2-Axle Bus	New	15500	6000	9500	100/0	88%	61.42	4.28	1.13	0.09	0.03	0.00	7	92.94	22.20	10.45	0.11	89%
2-Axle Bus	New	16000	6000	10000	100/0	84%	83.41	5.10	1.25	0.09	0.03	0.00	7	88.71	27.43	15.68	0.17	134%
2-Axle Bus	New	17000	6000	11000	100/0	77%	164.45	7.41	1.54	0.10	0.03	0.00	7	81.32	45.70	33.95	0.35	289%
2-Axle Bus	New	18000	6000	12000	100/0	71%	332.36	10.94	1.90	0.12	0.03	0.00	7	75.07	80.72	68.98	0.68	587%
2-Axle Truck	Current	14200	6000	8200	100/0	-	23.73	2.25	0.74	0.07	0.02	0.00	21	318.21	35.23	-	-	-
2-Axle Truck	New	14800	6000	8800	100/0	94%	42.81	3.43	0.99	0.08	0.03	0.00	21	298.73	53.06	17.83	0.06	51%
2-Axle Truck	New	15500	6000	9500	100/0	88%	61.42	4.28	1.13	0.09	0.03	0.00	21	278.82	66.60	31.36	0.11	89%
2-Axle Truck	New	16000	6000	10000	100/0	84%	83.41	5.10	1.25	0.09	0.03	0.00	21	266.14	82.28	47.05	0.17	134%
2-Axle Truck	New	17000	6000	11000	100/0	77%	164.45	7.41	1.54	0.10	0.03	0.00	21	243.96	137.09	101.86	0.35	289%
2-Axle Truck	New	18000	6000	12000	100/0	71%	332.36	10.94	1.90	0.12	0.03	0.00	21	225.20	242.16	206.93	0.68	587%
3-Axle Truck	Current	21000	6000	15000	50/50	-	26.11	2.85	1.03	0.10	0.04	0.01	21	318.21	42.95	-	-	-
3-Axle Truck	New	22000	6000	16000	50/50	94%	39.91	3.70	1.19	0.11	0.04	0.01	21	299.49	54.56	11.61	0.04	27%
3-Axle Truck	New	23000	6000	17000	50/50	89%	47.43	4.18	1.29	0.11	0.04	0.01	21	282.86	59.02	16.07	0.07	37%

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

						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%					
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	-	62.54	6.65	2.45	0.29	0.09	0.02	4	23.57	15.03	-	-	-
3-Axle Bus	New	20600	6000	14600	60/40	91%	109.12	9.64	3.10	0.33	0.09	0.03	4	21.44	19.90	4.88	0.26	32%
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	New	22700	6000	16700	60/40	76%	216.23	14.32	3.89	0.37	0.10	0.03	4	18.02	27.24	12.22	0.67	81%
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%
3-Axle Bus	New	22700	6000	16700	55/45	83%	141.27	11.57	3.49	0.35	0.10	0.03	4	19.63	22.03	6.52	0.39	42%
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%
2-Axle Bus	New	15500	6000	9500	100/0	88%	149.56	10.59	2.86	0.26	0.07	0.02	4	20.65	22.01	9.56	0.47	77%
2-Axle Bus	New	16000	6000	10000	100/0	84%	203.11	12.60	3.17	0.28	0.07	0.02	4	19.71	26.54	14.09	0.68	113%
2-Axle Bus	New	17000	6000	11000	100/0	77%	400.47	18.32	3.90	0.31	0.07	0.02	4	18.07	42.14	29.69	1.38	239%
2-Axle Bus	New	18000	6000	12000	100/0	71%	809.34	27.04	4.82	0.34	0.08	0.02	4	16.68	71.63	59.18	2.67	475%
2-Axle Truck	Current	14200	6000	8200	100/0	-	57.79	5.57	1.88	0.21	0.06	0.02	11	64.82	34.23	-	-	-
2-Axle Truck	New	14800	6000	8800	100/0	94%	104.25	8.48	2.50	0.25	0.07	0.02	11	60.85	49.59	15.36	0.27	45%
2-Axle Truck	New	15500	6000	9500	100/0	88%	149.56	10.59	2.86	0.26	0.07	0.02	11	56.80	60.52	26.29	0.47	77%
2-Axle Truck	New	16000	6000	10000	100/0	84%	203.11	12.60	3.17	0.28	0.07	0.02	11	54.21	72.99	38.75	0.68	113%
2-Axle Truck	New	17000	6000	11000	100/0	77%	400.47	18.32	3.90	0.31	0.07	0.02	11	49.70	115.88	81.65	1.38	239%
2-Axle Truck	New	18000	6000	12000	100/0	71%	809.34	27.04	4.82	0.34	0.08	0.02	11	45.87	196.98	162.75	2.67	475%
3-Axle Truck	Current	21000	6000	15000	50/50	-	63.58	7.03	2.61	0.31	0.09	0.03	11	64.82	42.97	-	-	-
3-Axle Truck	New	22000	6000	16000	50/50	94%	97.19	9.13	3.02	0.33	0.09	0.03	11	61.01	52.69	9.71	0.19	23%
3-Axle Truck	New	23000	6000	17000	50/50	89%	115.49	10.33	3.27	0.34	0.09	0.03	11	57.62	56.34	13.37	0.28	31%

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

						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%					
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	-	62.54	6.65	2.45	0.29	0.09	0.02	5	29.46	18.78	-	-	-
3-Axle Bus	New	20600	6000	14600	60/40	91%	109.12	9.64	3.10	0.33	0.09	0.03	5	26.80	24.88	6.10	0.26	32%
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	New	22700	6000	16700	60/40	76%	216.23	14.32	3.89	0.37	0.10	0.03	5	22.52	34.05	15.27	0.67	81%
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%
3-Axle Bus	New	22700	6000	16700	55/45	83%	141.27	11.57	3.49	0.35	0.10	0.03	5	24.54	27.53	8.15	0.39	42%
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%
2-Axle Bus	New	15500	6000	9500	100/0	88%	149.56	10.59	2.86	0.26	0.07	0.02	5	25.82	27.51	11.95	0.47	77%
2-Axle Bus	New	16000	6000	10000	100/0	84%	203.11	12.60	3.17	0.28	0.07	0.02	5	24.64	33.18	17.62	0.68	113%
2-Axle Bus	New	17000	6000	11000	100/0	77%	400.47	18.32	3.90	0.31	0.07	0.02	5	22.59	52.67	37.11	1.38	239%
2-Axle Bus	New	18000	6000	12000	100/0	71%	809.34	27.04	4.82	0.34	0.08	0.02	5	20.85	89.54	73.98	2.67	475%
2-Axle Truck	Current	14200	6000	8200	100/0	-	57.79	5.57	1.88	0.21	0.06	0.02	14	82.50	43.57	-	-	-
2-Axle Truck	New	14800	6000	8800	100/0	94%	104.25	8.48	2.50	0.25	0.07	0.02	14	77.45	63.11	19.54	0.27	45%
2-Axle Truck	New	15500	6000	9500	100/0	88%	149.56	10.59	2.86	0.26	0.07	0.02	14	72.29	77.02	33.45	0.47	77%
2-Axle Truck	New	16000	6000	10000	100/0	84%	203.11	12.60	3.17	0.28	0.07	0.02	14	69.00	92.89	49.32	0.68	113%
2-Axle Truck	New	17000	6000	11000	100/0	77%	400.47	18.32	3.90	0.31	0.07	0.02	14	63.25	147.49	103.92	1.38	239%
2-Axle Truck	New	18000	6000	12000	100/0	71%	809.34	27.04	4.82	0.34	0.08	0.02	14	58.38	250.71	207.14	2.67	475%
3-Axle Truck	Current	21000	6000	15000	50/50	-	63.58	7.03	2.61	0.31	0.09	0.03	14	82.50	54.70	-	-	-
3-Axle Truck	New	22000	6000	16000	50/50	94%	97.19	9.13	3.02	0.33	0.09	0.03	14	77.65	67.06	12.36	0.19	23%
3-Axle Truck	New	23000	6000	17000	50/50	89%	115.49	10.33	3.27	0.34	0.09	0.03	14	73.33	71.71	17.02	0.28	31%

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

						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%					
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	-	62.54	6.65	2.45	0.29	0.09	0.02	7	41.25	26.30	-	-	-
3-Axle Bus	New	20600	6000	14600	60/40	91%	109.12	9.64	3.10	0.33	0.09	0.03	7	37.52	34.83	8.53	0.26	32%
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	New	22700	6000	16700	60/40	76%	216.23	14.32	3.89	0.37	0.10	0.03	7	31.53	47.68	21.38	0.67	81%
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%
3-Axle Bus	New	22700	6000	16700	55/45	83%	141.27	11.57	3.49	0.35	0.10	0.03	7	34.35	38.55	11.41	0.39	42%
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%
2-Axle Bus	New	15500	6000	9500	100/0	88%	149.56	10.59	2.86	0.26	0.07	0.02	7	36.14	38.51	16.73	0.47	77%
2-Axle Bus	New	16000	6000	10000	100/0	84%	203.11	12.60	3.17	0.28	0.07	0.02	7	34.50	46.45	24.66	0.68	113%
2-Axle Bus	New	17000	6000	11000	100/0	77%	400.47	18.32	3.90	0.31	0.07	0.02	7	31.63	73.74	51.96	1.38	239%
2-Axle Bus	New	18000	6000	12000	100/0	71%	809.34	27.04	4.82	0.34	0.08	0.02	7	29.19	125.35	103.57	2.67	475%
2-Axle Truck	Current	14200	6000	8200	100/0	-	57.79	5.57	1.88	0.21	0.06	0.02	21	123.75	65.35	-	-	-
2-Axle Truck	New	14800	6000	8800	100/0	94%	104.25	8.48	2.50	0.25	0.07	0.02	21	116.17	94.67	29.32	0.27	45%
2-Axle Truck	New	15500	6000	9500	100/0	88%	149.56	10.59	2.86	0.26	0.07	0.02	21	108.43	115.53	50.18	0.47	77%
2-Axle Truck	New	16000	6000	10000	100/0	84%	203.11	12.60	3.17	0.28	0.07	0.02	21	103.50	139.34	73.99	0.68	113%
2-Axle Truck	New	17000	6000	11000	100/0	77%	400.47	18.32	3.90	0.31	0.07	0.02	21	94.88	221.23	155.88	1.38	239%
2-Axle Truck	New	18000	6000	12000	100/0	71%	809.34	27.04	4.82	0.34	0.08	0.02	21	87.58	376.06	310.71	2.67	475%
3-Axle Truck	Current	21000	6000	15000	50/50	-	63.58	7.03	2.61	0.31	0.09	0.03	21	123.75	82.04	-	-	-
3-Axle Truck	New	22000	6000	16000	50/50	94%	97.19	9.13	3.02	0.33	0.09	0.03	21	116.47	100.58	18.54	0.19	23%
3-Axle Truck	New	23000	6000	17000	50/50	89%	115.49	10.33	3.27	0.34	0.09	0.03	21	110.00	107.57	25.52	0.28	31%

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

APPENDIX B: Review of Pavement Impact Assessment on Wellington City Council Network by Opus International Consultants Ltd

This section covers a review of the Double deck bus pavement impact assessment by Opus International Consultants Ltd for the Wellington City Council. The report is dated 12 October 2015.

The objective of the report is to assess the impact of the WCC replacing its aging fleet of electric trolley buses with 2 axle double deck buses.

The authors of the report are correct in stating that the estimation of pavement wear due to an increase in vehicle mass is not an exact science. Many of the pavement defects that may arise from an increase in vehicle mass are not covered / predicted by the design or pavement deterioration process. These types of defects are likely to arise at bus stops and intersections.

1. Bus Fleet ESA analysis

The first part of the report looks at the change in ESA values for the current bus fleet and potential future configurations of the bus fleet. Four cases are considered:

- current fleet,
- a direct switch of 60 trolley buses with 60 double deck buses loaded to the new VDAM rules,
- a direct switch of 60 trolley buses with 60 double deck buses loaded to the maximum passenger capacity, which will result in the bus significantly exceeding the VDAM limits, and
- a reduced number of double deck buses carrying the current passenger volume.

The report analyses the makeup of the bus fleet and ultimately calculates a weighted ESA value for the bus fleet for the various options listed above. The methodology used in this analysis is sound and in line with current thinking/practice. The ESA calculations are based on an ESA damage exponent of 4.

Our experience with this approach is that the impact of the heavier vehicles is diluted across the entire bus fleet. If specific buses are operating on a known network, then a targeted fleet composition and calculation should be used instead.

2. Pavement Wear

The change in pavement wear is calculated by determining the percentage change in ESA loading due to the changes in the bus fleet. The achieved pavement lives in WCC are used, along with typical maintenance activities and costs that would be expected for a bus route. These findings/costs would be considered typical and in line with costs and pavement lives from other major urban centres.

As mentioned above, the dilution of the changed ESA will influence the pavement wear rates and allocation of costs on the network.

3. Bus Routes

The major bus routes (9 in total) were identified and summarised by length and classification. No analysis on route specific RAMM treatment lengths/pavement condition was undertaken as the authors stated that they did not have sufficient information to undertake this analysis. An estimate of bus traffic on each level of pavement hierarchy was made, allowing for route overlaps etc.

The report uses the assumption that all the buses travel over the entire network. The report does not state what percentage of the bus traffic on the specified routes is diesel powered compared to the trolley buses.

4. Future Fleet Configuration Cases

The report authors have made assumptions on the temporal and spatial changes in vehicle loadings as the buses travel further away from the CBD. This information is presented as a weighted ESA value for each level of pavement hierarchy. The methodology used for this analysis is appropriate given the level of detail that the report goes into and the type of data that the authors had access to.

Future - Case 3 (same total passenger capacity) could be considered unlikely as a reduced service frequency would be the outcome of this option and this has the potential to reduce the desirability of the bus service to the passengers.

5. Effect on Pavement surface life and cost

An analysis has been undertaken at a road hierarchy level to determine the split between bus and general HCV traffic. In some cases this has resulted in more buses than total HCV vehicles. This appears to have arisen due to the lack of refinement in some of the assumptions across the hierarchy. For each future case, the total HCV values have been recalculated and the resulting change in pavement life has been determined. The change in pavement life has been incorporated into the pavement life/renewal cost model to determine the change in overall maintenance costs on the bus network pavement.

Apart from the lack of refinement in splitting out the bus traffic, the methodology used is sound given the data that the authors have used in this study.

The assessment of pavement lives is a lag indicator, i.e. it is based on past performance and traffic volumes, the impact of the proposed heavier vehicles on rates of pavement wear is uncertain as historically the ESA calculations have been based on axle weights that are at or below the standard axle weights for each axle group. The proposed vehicle masses will impose loads on the pavement that are an extrapolation of the current load levels and as such, predictions of the future performance/response could be considered less certain than the status quo.

6. Bus Stops and Intersections

A commentary is made on the pavement wear issues at bus stops, the achieved pavement lives at bus stops and the likely/required maintenance activities at bus stops. Based on the proposed changes in pavement loading, an assessment of the additional bus stop maintenance costs is estimated.

Pavement wear at bus stops is likely to be more weighted towards load related aspects (shoving/shear type failures) rather than repetition related aspects, therefore the assumption that a reduced number of heavier vehicles is unlikely to cause any increase in cost compared to the status quo should be reviewed.

7. Overall Assessment of the Report

The analysis contained in the report is based on changes in pavement wear based on the fourth power law and this is applied to the observed pavement lives and maintenance costs. This level of analysis is only going to give an overall network assessment as it is based on a large number of assumptions and average values across the identified bus network. The assumptions made and datasets/sources that were used were pragmatic and matched the detail of the analysis/modelling that was used.

A more in depth study could be completed using the dTIMS model and the information contained in the WCC RAMM database, particularly the pavement strength data, however the output from this level of modelling is still only going to give a network level assessment and may not offer a better or more confident answer. Better fleet mix definition for the conversion of conventional to HPMV vehicles, and count data would also be required.

The critical issue around increased axle loadings is that pavement inspections need to be more frequent and complete and that maintenance or rehabilitation is prompt and timely because if a pavement starts to exhibit signs of deterioration under the increased axle loading, the rate of the deterioration is likely to be rapid and will propagate quickly.

Based on our assessment of the analysis presented in the report, the pavement wear/cost impacts resulting from the replacement of the trolley bus fleet with double decker buses is likely to lie somewhere between Future Cases 1 (VDAM compliant) and 2 (fully loaded), i.e. between $0.6M and $1.3M per annum. It is our opinion that Future Case 3 is not feasible due to the reduction in service that would be required to realise the efficiencies assumed for this option.

APPENDIX C: Assessment of Pavement Impact from Increased Axle Loads (using a weighted axle spectrum in dTIMS)

1. Calculation of the ESA/HCV2 Factor

The dTIMS model uses the ESA/HCV2 factor as an input to the pavement wear component of the maintenance demand modelling process. The equivalent standard axle (ESA) is defined as the number of passes of an axle (or axle group) with a standard mass that causes the same amount of pavement wear as an axle (or axle group) with a specified mass. The heavy commercial vehicle 2 (HCV2) is a heavy commercial vehicle that is either a truck and trailer, or articulated vehicle with or without a trailer, with 5 or more axles in total.

In the RAMM database the HCV2 variable is recorded as a percentage of the AADT and is reported for each treatment length. In addition to the HCV2 percentage, the sum of the HCV1 (3 or 4 axle rigid trucks or articulated vehicles) and HVC2 percentages are stored as the HCV percentage. Data also exists for light commercial vehicles (LCV), medium commercial vehicles (MCV, 2 axle trucks) and buses however this data does not appear or correlate within the HCV field, therefore it is assumed that the applicability or source of this secondary data could be considered unreliable.

In order to examine the impact of increased axle loads on the selected network, the aggregated data from the NZTA WIM sites for the year ended 31 December 2013 was used to derive an ESA/HCV2 relationship. The data used in this analysis was the individual datasets from each WIM station and included the axle weight distributions for the different axle groups (SAST, SADT, TADT, etc.) and the vehicle counts for the various vehicle classifications.

The data was collated as described in the subsequent paragraphs:

1.1. Axle weight spectrum

A weighted axle weight spectrum was calculated using the axle weight spectrums from each weight-in-motion (WIM) station and the percentage of vehicles recorded at each NZTA WIM station. The dataset was based on 10 kN bins for each axle type. The heavy vehicle axle group types are:

- single axle with single tyres (SAST)
- single axle with dual tyres (SADT)
- tandem axle with single tyres (TAST)
- tandem axle with dual tyres (TADT)
- triaxle with dual tyres (TRDT)
- quad-axle with dual tyres (QADT).

The percentage split of heavy vehicles between the six WIM stations is shown in Table 0-1. The Drury WIM station recorded almost 50% of the total traffic volume. The weighted axle load spectrum is shown in Table 0-2.

Table 0-1: HCV split across WIM stations

Site	Percent Split
00200176 (Te Puke)	18.4
01N00463 (Drury)	48.1
01N00628 (Tokoroa)	15.7
01S00285 (Waipara)	6.0
00500259 (Eskdale)	6.3
03500321 (Hamanatua Bridge)	5.4

Table 0-2: Weighted axle load spectrum

Load Bin (kN)	SAST	SADT	TADT	TSST	TRDT	QADT
10	0.017	0.055	0.001			
20	0.276	0.381	0.028			
30	0.170	0.237	0.039		0.002	
40	0.100	0.115	0.072	0.001	0.014	0.002
50	0.204	0.080	0.073	0.007	0.043	0.010
60	**0.200**	0.059	0.073	0.027	0.069	0.039
70	0.030	0.039	0.068	0.137	0.087	0.065
80		**0.022**	0.066	0.263	0.084	0.094
90		0.011	0.079	**0.257**	0.069	0.076
100		0.001	0.090	0.210	0.064	0.055
110			0.102	0.078	0.060	0.048
120			0.095	0.012	0.061	0.048
130			0.077		0.060	0.041
140			**0.064**		0.064	0.045
150			0.045		0.058	**0.046**
160			0.022		0.064	0.047
170			0.008		0.065	0.049
180					**0.056**	0.062
190					0.040	0.060
200					0.018	0.096
210					0.008	0.072
220						0.032
230						0.011
240						0.003
Sum	**0.997**	**0.999**	**1.002**	**0.992**	**0.986**	**0.999**
Standard Load (kN)	53	80	135	90	181	150

1.2. ESA spectrum

Conversion of the traffic/axle weight spectrums to a single design value has historically been done using the fourth power law. This relationship uses a power exponent value of 4 to determine the damaging effect of a specified axle load. Research from the Transport Agency's Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF) showed a relationship between pavement wear and axle load that did not conform to the historical "fourth power law" damage equation. Instead, the damage power varied depending on the strength of the pavement, the damage in the stronger pavements was best represented by a lower exponent and weaker pavements were best represented by higher exponent values.

An output from this research has been a relationship that determines the damage exponent as a function of the pavement strength. This relationship will be explained further in Section 1.4 below.

The weighted axle weight spectrum was then used to calculate the ESA for each weight bin and axle group type. The reference axle weights for each axle type are those given in Tables 7.5 and 7.6 of the Austroads Pavement Design Guide (APDG) and are included in Appendix C-A for ease of reference. Based on the observation of traffic flows on the network by the author, the majority of quad axle groups are equipped with wide single tyres. Therefore the standard axle load for the quad axle group was based on the reference load for a wide single tyre rather than a dual tyre axle. This produces a more aggressive ESA relationship as the reference load for a quad axle with single tyres is 150 kN compared to 221 kN for a dual tyre configuration (refer Appendix C-A). Historic research proved that these tyres cause an increase in pavement contact and in turn generate graeter pavement damage and permanent strains in pavement layers compared to conventional truck tyres. (Myers et al. 1999, Salgado. 2002).

The ESA spectrum for each axle group was converted into a weighted ESA value based on the percentage distribution in each weight bin. This consolidation gave a single ESA value for each axle group.

The ESA spectrum calculation was repeated for a range of exponent values (n=1.5, 2.0, 2.5…6.5) as this information was required for the later analysis.

1.3. ESA/Truck type spectrum

An average ESA value for each truck classification was calculated by multiplying the number and type of axle groups by the respective ESA value for each axle group. The axle group spectrum was developed based on the axle group configuration for each vehicle type. For example a R12T22 vehicle has 1 single tyre, single axle group and 3 dual tyre, dual axle groups.

The resulting ESA/truck type value was then weighted by the percentage distribution for that truck type. A single ESA vale for each of the MCV/HCV1/HCV2 groupings was calculated by summing the weighted ESA values for each truck type in their respective grouping.

The dTIMS analysis uses the ESA/HCV2 value as an input so a modified ESA/HCV2 value was determined by dividing the sum of the ESA/truck grouping values by the percentage of HCV2 vehicles in the truck type table. This ensured that ESA contribution of the entire truck fleet was assigned to the HCV2 truck grouping and was thus factored into the pavement wear model.

The split of truck groupings is listed in Table 0-3.

Table 0-3: Distribution of Truck Groupings

Truck Groupi	Percentage (%)
MCV	25
HCV1	19
HCV2	56
Total	100

This calculation was also repeated for the range of damage exponents.

The resulting ESA/n relationship is shown in Figure 0-1. The general shape of the relationship initially appears counterintuitive with higher damage values at the lower and upper range of the damage exponent. This is explained by examining the spread of axle weights. There is a significant percentage of axle loads that is less than the standard (and legal) limit across all the axle groups. At low values of “n”, the axle weights that are less than the standard axle load contribute a reasonable amount of the total damage. In addition, axle loads that are greater than the standard axle load do not contribute significantly to the total damage. The axle loads that are greater than the standard axle loads are predominately in the quad axle group as a lower standard group load was selected due to the predominance of wide single tyres.

As the damage exponent increases, the contribution of the axle loads that are less than the standard axle loads decreases and the contribution of the axle loads that are greater than the standard load increases. Because the quad axle group contain a significant proportion of axle group loads that are greater than the relevant standard axle load and the weight rang extends significantly above the standard load, this group dominates the higher damage exponent values.

The best fit equation for the relationship was a third order polynomial.

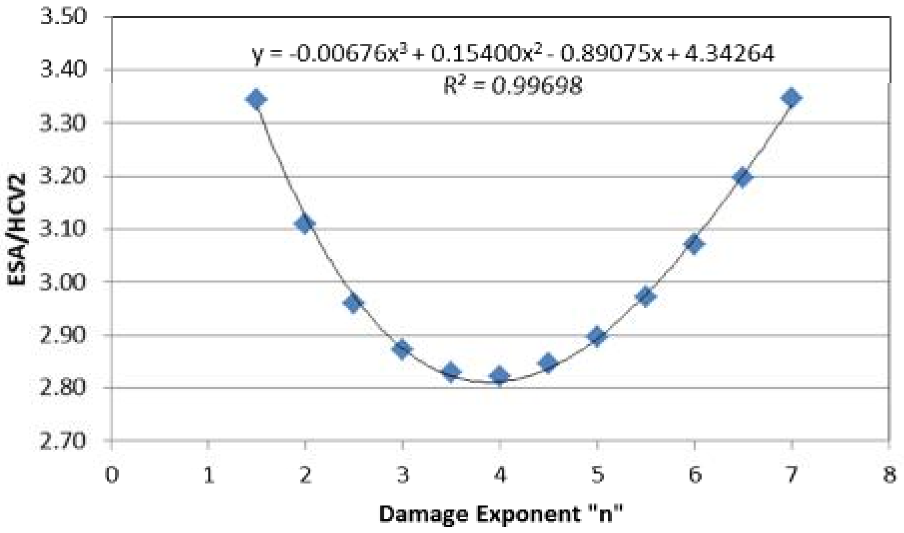


Figure 0-1 ESA/HCV2 value as a function of damage exponent.

1.4. ESA as a function of SNP and damage exponent ("n")

The dTIMS pavement wear model used in this study used a dynamic n equation based on the strength of the pavement.

The pavement strength is represented by the structural number (SNP) of the pavement which is based on the summation of empirical layer coefficients from test pit layer information and/or Falling Weight Deflectometer (FWD) tests. SNP is a fundamental parameter for network analysis and is currently the only measure that gives asset managers an overall indiction of how much capacity / life can be expected from their networks. Over the years researchers have developed algorithms for calculating the SNP from falling weight deflectometer measurements to enable network level assessments of pavement strength. The SNP method of pavement strength assessment can provide a consistent measure across a network, but is not an appropriate measure at a project level assessment as site specific conditions need to be considered at a scale that is generally not available at a network wide level.

The relationship between the SNP value and pavement deflection developed by Salt (2009) is (Equation 2, Opus 2010):

$$SNP = 112(D_0) + 47(D_0 - D_{900})^{-0.5} - 56(D_0 - D_{1500})^{-0.5} - 0.4 \quad \text{Eqn 0-1}$$

Where SNP = Pavement Structural Number
D_0 = FWD central deflection (μm) (normalised to 40 kN)
D_{900} = FWD deflection 900 mm from the load plate (μm) (normalised to 40 kN)
D_{1500} = FWD deflection 1500 mm from the load plate (μm) (normalised to 40 kN)

This relationship has been calibrated for the New Zealand network environment.

Research from CAPTIF showed a relationship between pavement wear and axle load that did not conform to the historical "fourth power law" damage equation. Instead, the damage power exponent was lower than 4 for stronger pavements and higher for weaker pavements. This finding makes sense in an engineering/materials based approach, i.e. stronger pavements are less sensitive to increases in axle loads whilst weaker pavements are more likely to show rapid increases in pavement wear even for small increases in axle loads. A relationship between SNP and damage exponent has been developed and is (Figure A1.2a, Opus 2010):

$$n = 51.62SNP^{-2.8832} \qquad \text{Eqn 0-2}$$

Where n = ESA power exponent
SNP = Pavement Structural Number

By combining equation 1-2 and the relationship between n and ESA/HCV2 as shown in Figure 0-1, a relationship can be derived to estimate the ESA/HCV2 value from SNP that incorporates the dynamic n relationship.

1.5. Impact on traffic distribution from take up of new axle group limits

In order to consider the impact on pavement wear that results from the change in axle group limits for a dual tyre, single axle (up to 11 tonnes) and dual tyre tandem axle group (up to 17 tonnes), the axle load spectrums for the single and tandem axle groups were modified to reflect a variable rate of adoption of the increased limits. The axle load spectrums from the WIM data is shown in Figure 0-2 and Figure 0-3. For the single axle spectrum, the bulk of the recorded axle loads are well below the loading limit. The implication of this is that at a network level there is unlikely to be a measureable impact on pavement wear due to increasing the limit on single axles. The impact is likely to show up on a specific route analysis where there is potentially a more significant contribution of the heavier single axles, i.e. on a tourist dominated route.

Likewise for the tandem axle groups, the majority of the axle loads are below the current limits. There is a noticeable quantum of axle loads above the Class 1 limit, however it is likely that a reasonable portion of these will be HPMV permitted vehicles as the upper limit for this group is currently 157 kN.

The following methodology was used to incorporate the potential uptake of increased axle group limits in the single and tandem axle configurations:

1. The weighted axle load sum was calculated and it was decided to keep this value constant, i.e. alter the weight distribution while keeping the freight task the same.
2. The uptake in the increase in axle group limits was based on the freight task at the current Class 1 limit weight bins – 80 kN for the single axle and 150 kN for the tandem axle group. As an example, for an uptake of 10%, the freight task at the Class 1 weight bin was reduced by 10% and this amount was added to the weight bin at the new limit (110 kN for single axles and 170 kN for tandem axles). In order to keep the total freight task unchanged, the peak value in the spectrum was reduced by the required amount. In order to keep the general shape of the axle weight distributions the same, a simplified linear approximation was fitted to the data with break points at the obvious changes in the data shape. Finally the quantities at the intermediate weight bins were determined.
3. The new axle load spectrums were used to calculate new ESA/Axle group values, which were then used to recalculate new ESA/HCV2 values for the ESA/HCV2-SNP equation.

This relationship is shown in

Figure 0-5 and shows a minor change in the overall relationship. As explained earlier, the higher uptake levels will have the biggest impact on the low strength pavements. The relationship developed for the dTIMS model is of the following form:

$$ESA/HCV2 = aSNP^b + cSNP^d + eSNP^f + g \quad \text{Eqn 0-3}$$

The coefficients for Equation 1-3 are listed in Table 0-4.

Table 0-4: Coefficients for ESA/HVCV2 – SNP relationship for the dTIMS model

Uptake	a	b	c	d	e	f	g
0%	-929.824	-8.6496	410.3522	-5.7664	-45.9805	-2.8832	4.34264
10%	-924.322	-8.6496	407.6875	-5.7664	-45.6749	-2.8832	4.20224
20%	-900.939	-8.6496	406.8349	-5.7664	-45.2062	-2.8832	4.20637
25%	-910.567	-8.6496	406.4085	-5.7664	-44.9724	-2.8832	4.20844
50%	-885.809	-8.6496	404.2502	-5.7664	-43.8011	-2.8832	4.21878
75%	-862.425	-8.6496	402.1185	-5.7664	-42.6304	-2.8832	4.22912

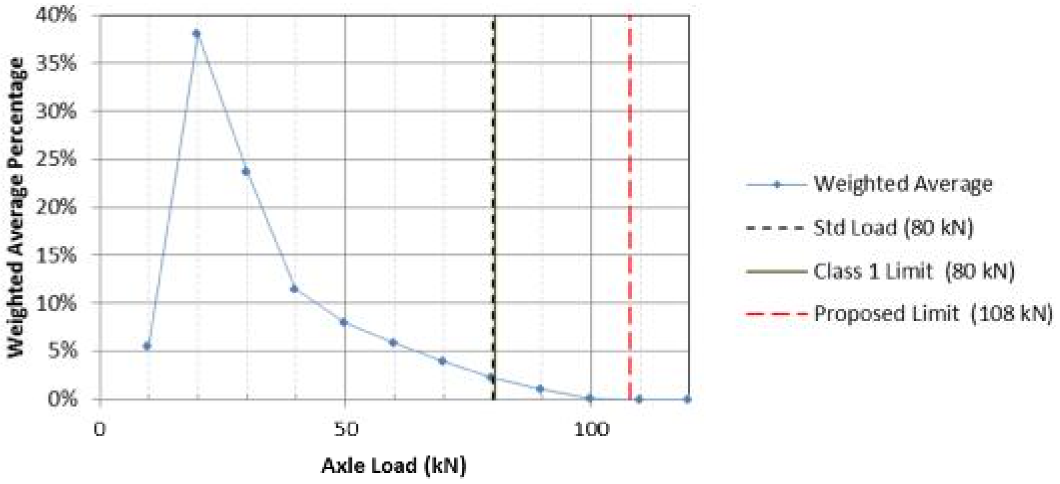


Figure 0-2 Axle load spectrum for the dual tyre, single axle group

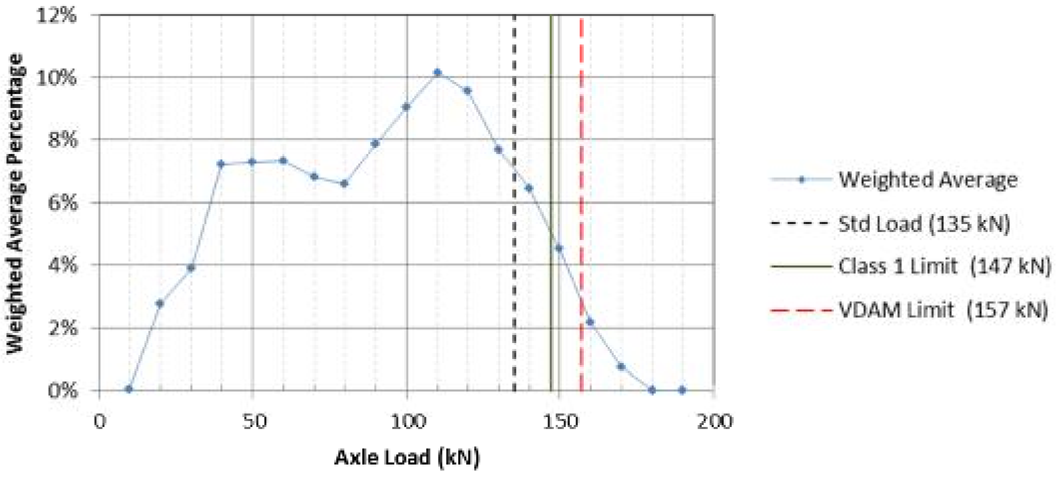


Figure 0-3 Axle load spectrum for the dual tyre, tandem axle group

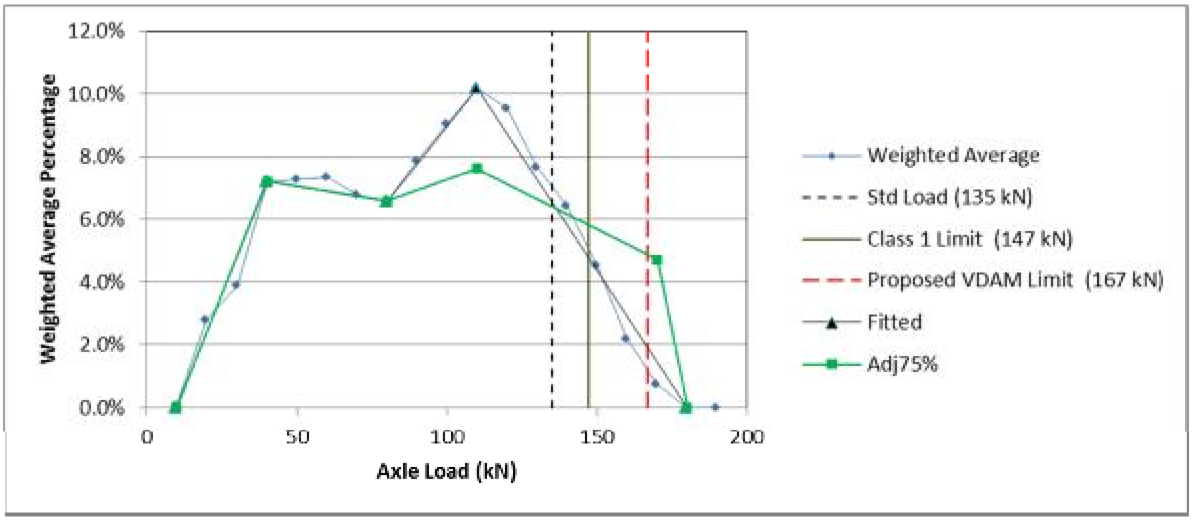


Figure 0-4 Altered axle load spectrum for the dual tyre, tandem axle group for 75% uptake

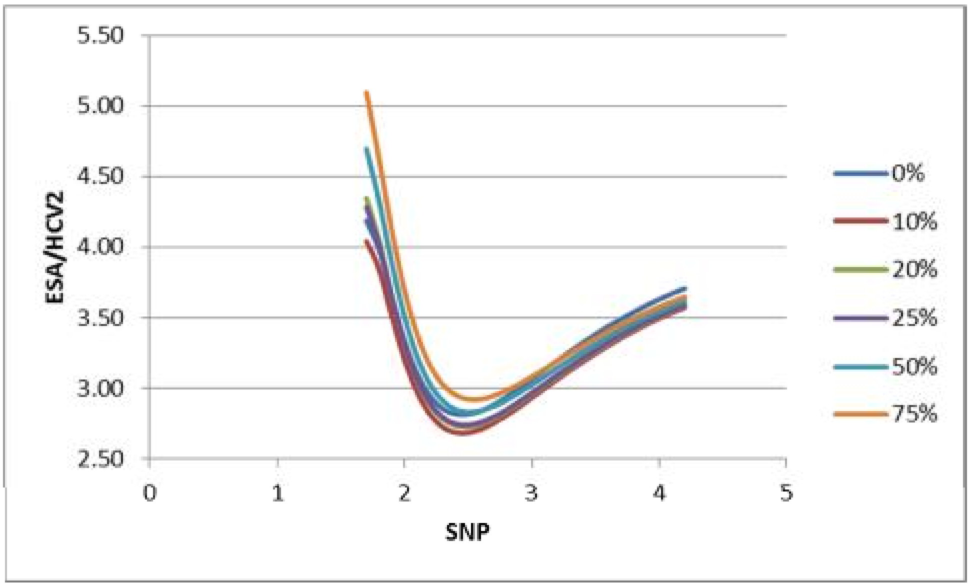


Figure 0-5 ESA/HCV2 - SNP relationship for various uptakes on new limits for single and tandem axle groups

2. Network SNP values

The distribution of the state highway Trance 2 and Wellington City Council (WCC) major bus networks pavement strength (SNP) values is shown in Figure 0-6. It can be seen that the WCC bus network is stronger than the Trance 2 network. This is to be expected as the WCC bus network is likely to have been upgraded over time due to the continual bus traffic and the need to maintain the pavement at a higher level of service for buses in order to attract and retain patronage on the bus services. In comparison, the Trance 2 state highway network is not the primary arterial network and as such contains more rural roads that are likely to contain weaker historical pavements that have not demonstrated an appropriate benefit cost ratio to qualify for upgrading/rehabilitation.

The higher SNP values on the WCC network are likely to result in a lower amount of wear compared to the Trance 2 network, however the maintenance and rehabilitation costs are likely to be higher due to the greater use of asphaltic concrete pavements in the urban network. The WCC network had a full FWD survey in 2014 so data confidence is good.

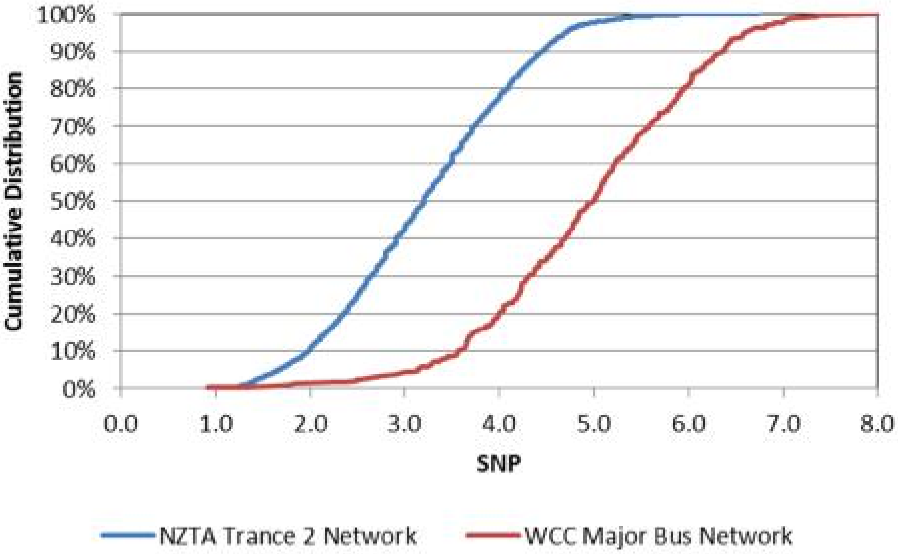


Figure 0-6 Cumulative distribution of Network SNP values

The pavement strengths across the different road classes for both the WCC ad Auckland networks are illustrated in Figure 0-7 and Figure 0-8 below.

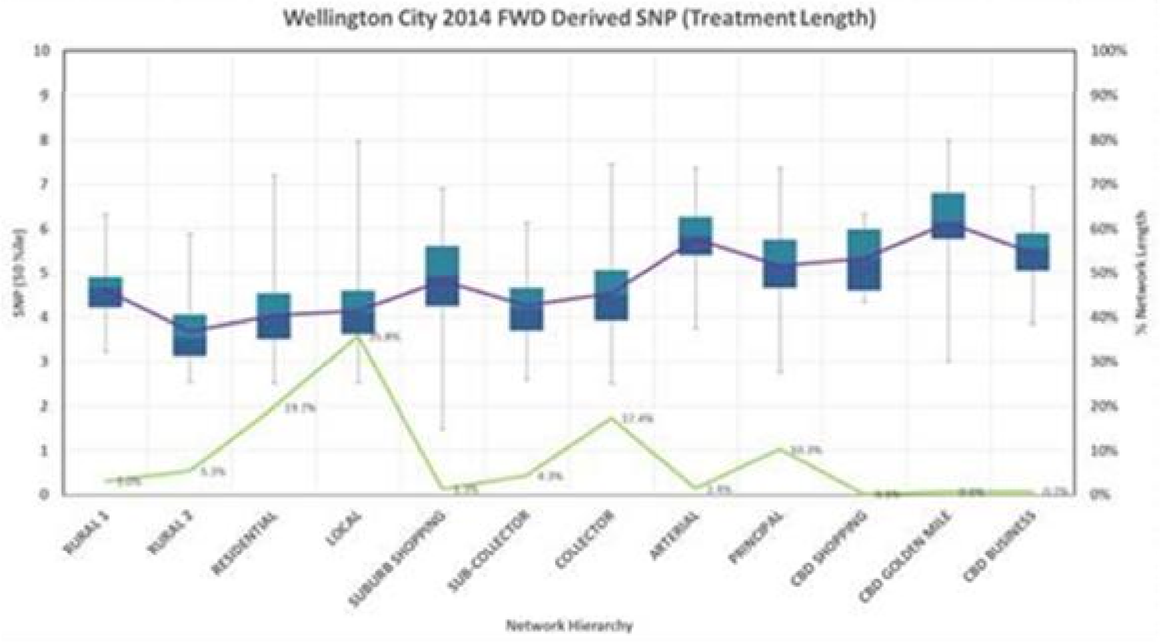


Figure 0-7 Wellington City Council Pavement Strength Distribution

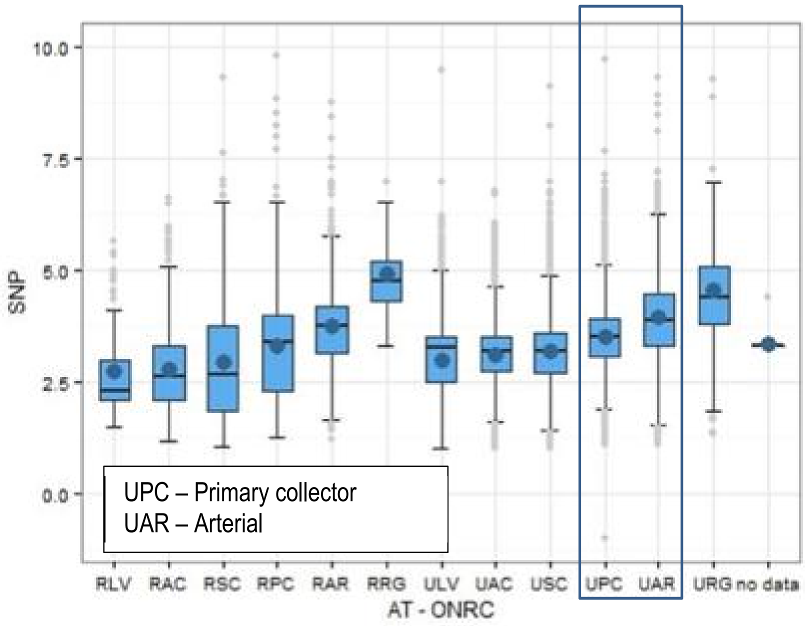


Figure 0-8 Auckland Transport Pavement Strength Distribution

The pavement on the WCC network are generally stronger compared to those on the Auckland Transport network. The strength difference is particularly evident on the arterial and primary collector routes which are expected to carry the majority of busses on both networks

3. Predicted Maintenance Requirements

Deighton dTIMS v8 was used to run a comparative trigger model analysis for the Zero uptake fleet mix versus a range of percentage uptake HPMV fleets over a 20-year analysis period. The trigger model analysis triggers on condition alone and is not investment constrained.

The previous 2015 HPMV Tranche2 model was used as a base with the 36 State Highway HPMV routes aggregated together as one route (2071.24 km). There was considerable overlap on the original 36 Tranche2 routes and this simplified the number of runs required while retaining the same treatment length footprint. The unit rates and model setup were derived from the 2015 HPMV Tranche 2 model for consistency, and are presented in Appendix C-C. A discount rate of 6% was used to be consistent with the Tranche 2 work, and the Bay of Plenty region growth rates adopted.

The revised HPMV fleet mix increase axle weights are accommodated in variations in the HCV2 term only. All other vehicle classes remain unchanged for this analysis. The revised ESA/HCV2 terms in Table 0-5 were used for each percentage uptake run (0% Baseline, 10%,20%,25%,50%,75%). From the analysis the difference in forecast planned and routine maintenance costs, and annual length treated (Rehabilitation & Reseal) summarised.

The outputs are presented in Table 0-5.

Table 0-5: Trigger Model dTIMS Differential Analysis – Base case vs HPMV (Aggregated Tranche 2 State Highway Routes)

Length Weighted SNP = 3.21		Reactive Mntce	Planned Maintenance over 20 Years (Rehabilitation and Reseal)						
			Planned Maintenance Cost ($/km/yr)			Rehabilitation Length		Reseal Length	
%uptake	Route Length (km)	Diff. ($/km/yr)	Base Case	Including HPMVs	Difference	Diff (km/yr)	% of Route Length	Diff (km/yr)	% of Route Length
10	2071.24	6	$17257	$17339	$82	0	0	-0.05	<1%
20	2071.24	10	$17257	$17368	$111	0	0	-0.09	<1%
25	2071.24	13	$17257	$17384	$127	0	0	-0.09	<1%
50	2071.24	19	$17257	$17510	$253	-0.01	<1%	-0.37	<1%
75	2071.24	23	$17257	$17612	$355	0.11	<1%	-0.71	<1%

3.1. Discussion

- The 2071.24 km HPMV Tranche 2 routes where aggregated in to a single network (or route), and the revised ESA/HCV2 expressions derived for each different percentage (%) uptake used for a trigger model run. The Base expression was the 0% uptake. The length weighted SNP for the aggregated route was 3.21.
- Over a 20-year period the forecast increase in pavement rehabilitation and resurfacing for the 10-75% uptake ESA/HCV2 expressions was less than 1% in km/year treatment forecast over the 0% uptake base case.

- The differential with increasing % uptake is in increased $/km/year of planned maintenance cost. Beyond 50% uptake there was a slight increase in rehabilitation and AC in the first 10 years and corresponding minor reduction in resurfacing length.
- There is higher rehabilitation in the first 10 years for the 50% & 75% uptakes. Over the 20 year period this was relatively insignificant in treated length but increases the cost/km as indicated in Table 2.
- At 75% uptake this would be an annual average increase of $736,839/year in planned maintenance and $2,833/year in routine maintenance for the 2071.24km route.

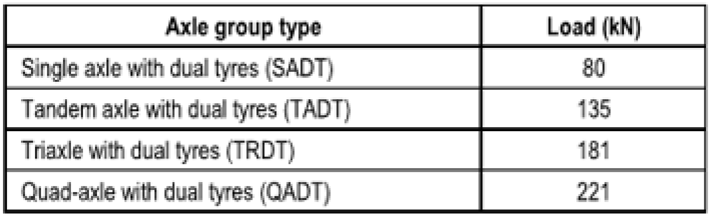
Appendix C-A: Austroads (2012) Reference Axle Load Tables

Reproduced from Austroads (2012) AGPT2-12, ISBN 978-1-921991-11-0

Heavy vehicle axle groups are:

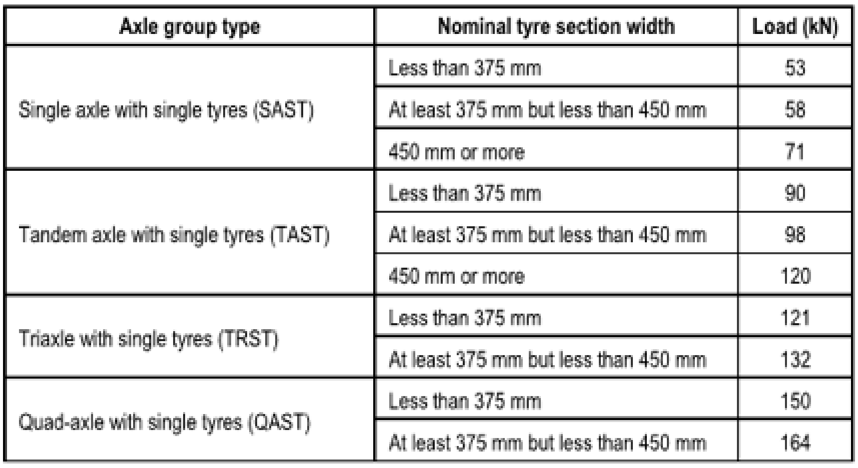
- Single axle with single tyres (SAST)
- Single axle with dual tyres (SADT)
- Tandem axle with single tyres (TAST)
- Tandem axle with dual tyres (TADT)
- Triaxle with dual tyres (TRDT)
- Quad-axle with dual tyres (QADT)

Table 7.5: Loads on axle groups with dual tyres which cause same damage as Standard Axle



Axle group type	Load (kN)
Single axle with dual tyres (SADT)	80
Tandem axle with dual tyres (TADT)	135
Triaxle with dual tyres (TRDT)	181
Quad-axle with dual tyres (QADT)	221

Table 7.6: Loads on axle groups with single tyres which cause same damage as a Standard Axle



Axle group type	Nominal tyre section width	Load (kN)
Single axle with single tyres (SAST)	Less than 375 mm	53
	At least 375 mm but less than 450 mm	58
	450 mm or more	71
Tandem axle with single tyres (TAST)	Less than 375 mm	90
	At least 375 mm but less than 450 mm	98
	450 mm or more	120
Triaxle with single tyres (TRST)	Less than 375 mm	121
	At least 375 mm but less than 450 mm	132
Quad-axle with single tyres (QAST)	Less than 375 mm	150
	At least 375 mm but less than 450 mm	164

Appendix C-B: NZ Transport Agency Tranche 2 HPMV Routes

Tranche Route Number	NZTA Route Description	State highway sections covered	Route Leng (km)
1	Hawkes Bay Boundary - Napier	SH2, SH2B, SH50A, SH50	98.
2	Napier - Gisborne	SH2, SH50, SH35	210.
3	Wakefield Street - Port of Napier	SH50, SH2B, SH2	6.
8	Gwavas Forest - PanPac	SH50, SH2	42.
9	Mohaka Forest - Whirinaki	SH2	60.
10	Mohaka Forest Putere - Whirinaki	SH2	75.
11	Waihua - SH5	SH2, SH50	107.
14	Taradale Road	SH50, SH2, SH50A	13.
15	Tangoio - Whirinaki	SH2	11.
16	Esk Forest Pohokura - Whirinaki	SH2, SH5	39.
17	Esk Forest Te Pohue - Whirinaki	SH2, SH5	51.
18	Kaweka Forest-Whirinaki	SH2, SH50	30.
20	Te Aroha - Tolaga Bay	SH35	114.
21	Mata Forest - Gisborne	SH35	89.
22	Waimate Forest-Matawhero	SH2, SH35	13.
28	Waihi-Tauranga	SH2	90.
29	Waitoa-Waihi	SH2, SH26	55.
30	Hamilton - Paeroa	SH1N, SH26, SH27	59.
31	Hamilton - SH27	SH1N, SH26	46.
35	Te Kuiti - Atiamuri	SH1N, SH3, SH30	110.
38	Atiamuri - Rotorua	SH5, SH30	37.
41	Edgecumbe - Whakatane	SH2, SH30	30.
45	Westport - Nelson	SH6, SH67, SH67A	238.
46	Darfield - Christchurch	SH73, SH74, SH75, SH76	70.
47	Hokitika - Nelson	SH6, SH7, SH69	326.
48	Nelson - Lyttelton	SH01S, SH6, SH7, SH65, SH74	447.
49	Nelson - Takaka	SH6, SH60	103.
50	Cape Foulwind - Stockton (Granity)	SH67 ,H67A	45.
51	Morrinsville - Tirau	SH26, SH27	48.
52	Matamata - SH29	SH24	14.
53	Opotiki - Edgecumbe	SH2	69.
55	Napier - Palmerston North	SH2, SH3, SH2B,SH50A, SH50	151.

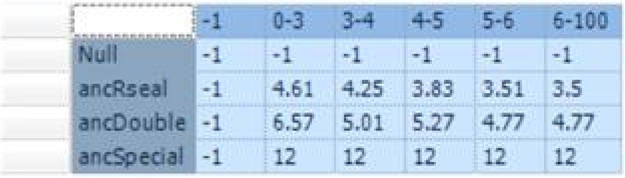
Tranche Route Number	NZTA Route Description	State highway sections covered	Route Leng (km)
57	Tokoroa - Mangakino	SH32	27.
59	Te Teko - Whakatane	SH30	20.
63	Tokaanu	SH41	22.
65	SH5/30 to Tikitere – Te Teko	SH30	47.

Appendix C-C: dTIMS Model Setup

Unit rates used were the same for all runs based on Unit Rates derived from the 2012 National Model run, and checked against recent State Highway modelling in the BOP and Hawkes Bay areas which had the bulk of the routes.

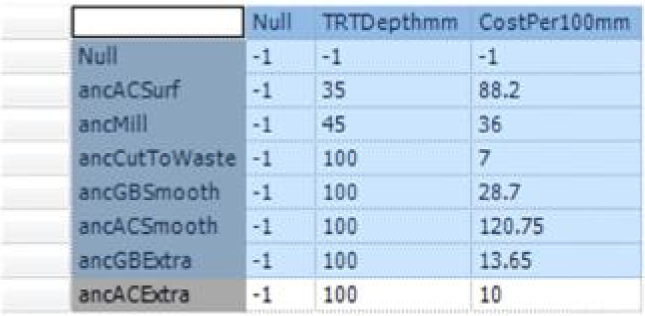
The following unit rates were applied in the models:

Unit Rate_Chipseal



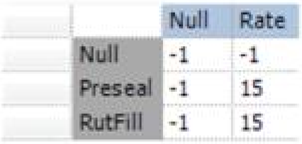
	-1	0-3	3-4	4-5	5-6	6-100
Null	-1	-1	-1	-1	-1	-1
ancRseal	-1	4.61	4.25	3.83	3.51	3.5
ancDouble	-1	6.57	5.01	5.27	4.77	4.77
ancSpecial	-1	12	12	12	12	12

Unit Rate_RehabilitationAC



	Null	TRTDepthmm	CostPer100mm
Null	-1	-1	-1
ancACSurf	-1	35	88.2
ancMill	-1	45	36
ancCutToWaste	-1	100	7
ancGBSmooth	-1	100	28.7
ancACSmooth	-1	100	120.75
ancGBExtra	-1	100	13.65
ancACExtra	-1	100	10

Unit Rate_Preseal



	Null	Rate
Null	-1	-1
Preseal	-1	15
RutFill	-1	15

APPENDIX D: Route Specific Pavement Life Prediction Tool

Rut depth modelling developed for NZTA CAPTIF research with the Rubicon Finite Element Model was used to calculate rut depth versus number of wheel passes of a defined load and tyre pressure. The rut depth calculations were undertaken for a range of tyre loads and tyre pressures from current legal load to the new proposed loads. These rut depth calculations were used to determine the pavement life for each different wheel load that can be used to determine the relative life when compared with the legal/reference load and thus a damage law exponent calculated.

Results of the rut depth modelling are shown below. It can be seen that increasing the tyre pressure does reduce the pavement life and this should be considered in the damage calculations.

Table 1 - Rut Depth Modelling Results on two pavement types at different wheel loads and tyre pressures

Analysis #	Depth (mm) (Average Quality Aggregate)	Sub-grade CBR	Load (kN)	Tyre Pressure (kPa)	Life (Millions of Axle Passes to 25mm rut)	Life (Millions of Axle Passes to 15mm rut)	mm of rut from one million passes (25mm failure rut)	mm of rut from one million passes (15mm failure rut)
1a	400	2	39.2	750	6.85	1.686	3.6	8.9
1b	400	2	39.2	825	5.41	0.964	4.6	15.6
1c	400	2	35.3	750	9.32	3.212	2.7	4.7
1d	400	2	35.3	825	8.03	2.531	3.1	5.9
1e	400	2	36.9	750	8.01	2.427	3.1	6.2
1f	400	2	36.9	825	6.80	1.800	3.7	8.3
1g	400	2	41.7	750	5.87	1.035	4.3	14.5
1h	400	2	41.7	825	4.47	0.459	5.6	32.7
1i	400	2	43.2	750	5.36	0.692	4.7	21.7
1j	400	2	43.2	825	4.01	0.369	6.2	40.6
1k	400	2	45.1	750	4.68	0.422	5.3	35.6
1l	400	2	45.1	825	3.40	0.255	7.3	58.9
1m	400	2	46.6	750	4.20	0.326	5.9	46.1
1n	400	2	46.6	825	3.00	0.179	8.3	83.9
1o	400	2	49.1	750	3.52	0.188	7.1	79.9
1p	400	2	49.1	825	2.42	0.090	10.3	167.4
1q	400	2	52	750	2.78	0.082	9.0	183.2
1r	400	2	52	825	1.61	0.051	15.5	293.9
1s	400	2	60	750	0.39	0.023	63.6	661.3
1t	400	2	60	825	0.15	0.022	167.2	697.4

Analysis #	Depth (mm) (Average Quality Aggregate)	Sub-grade CBR	Load (kN)	Tyre Pressure (kPa)	Life (Millions of Axle Passes to 25mm rut)	Life (Millions of Axle Passes to 15mm rut)	mm of rut from one million passes (25mm failure rut)	mm of rut from one million passes (15mm failure rut)
2a	400	8	35.3	750	22.39	11.867	1.1	1.3
2c	400	8	36.9	750	21.86	11.524	1.1	1.3
2e	400	8	39.2	750	21.08	11.019	1.2	1.4
2g	400	8	41.7	750	20.28	10.500	1.2	1.4
2i	400	8	43.2	750	19.79	10.183	1.3	1.5
2j	400	8	43.2	825	16.53	8.326	1.5	1.8
2k	400	8	45.1	750	19.22	9.818	1.3	1.5
2l	400	8	45.1	825	16.03	8.006	1.6	1.9
2m	400	8	46.6	750	18.73	9.505	1.3	1.6
2o	400	8	49.1	750	18.02	9.044	1.4	1.7
2q	400	8	52.0	750	17.18	8.503	1.5	1.8
2s	400	8	60.0	750	15.11	7.169	1.7	2.1

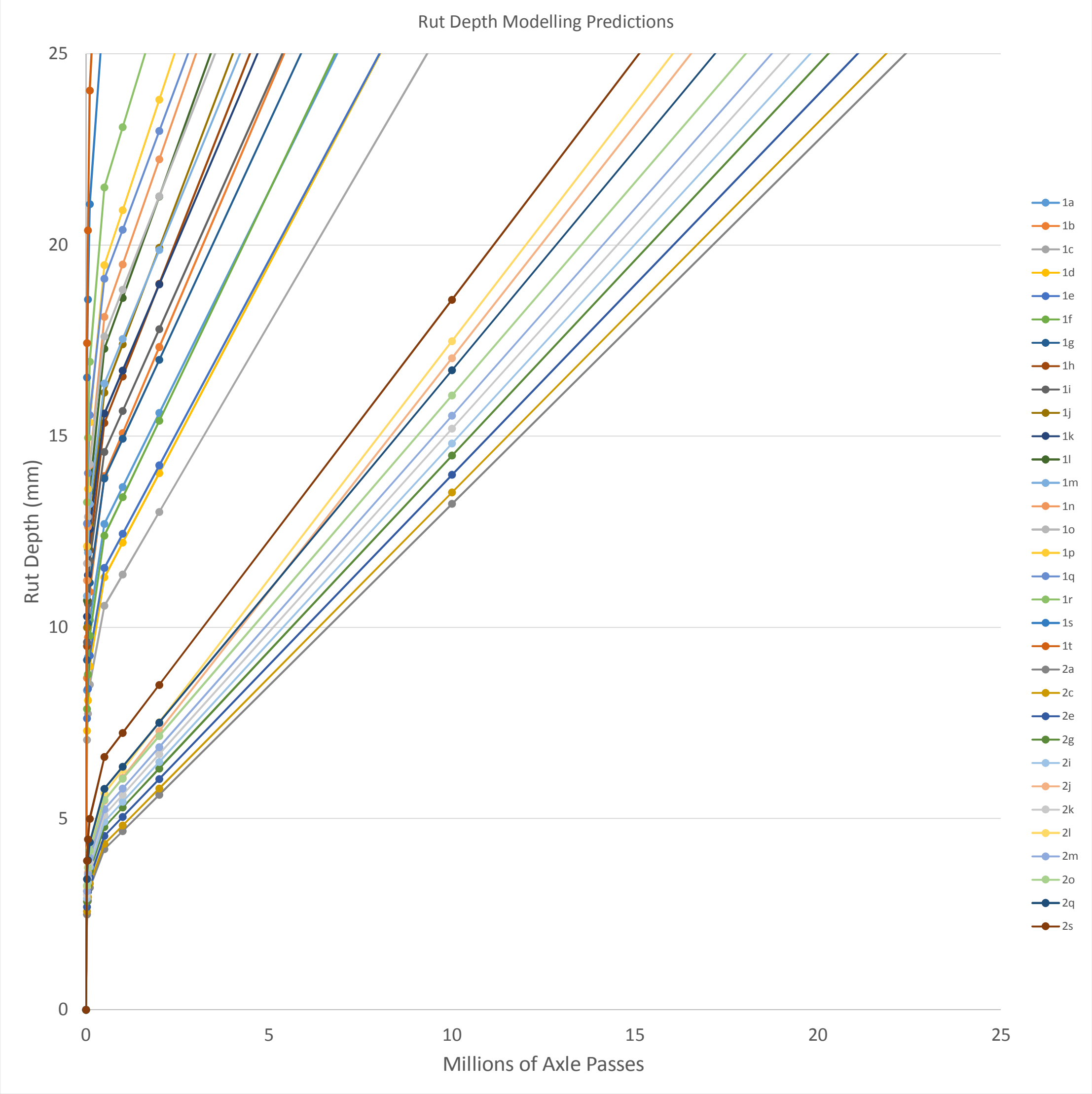


Figure 1: Rut Depth Modelling Predictions for a Range of Wheel Loads and Tyre Pressures as given in the table above

This prediction method will be valuable in determining the expected impact in pavement wear when vehicles with increased axle loads are introduced on a specific route with known pavement strength and composition. This approach may be refined to include various pavement configurations with different pavement strengths and material quality. Costs associated with repairs on the different pavement types under different vehicle type and loading could also be developed to improve the application of this approach.

Table 2: Relative Pavement Damage for Each Different Wheel Load Compared with an 8 tonne axle load

Wheel Load (kN)	Equivalent Single Axle Load (Tonnes)	Tyre Pressure (kPa)	% increase in pavement damage - weak pavement	% increase in pavement damage - strong pavement	Damage Exponent (weak pavement)	Damage Exponent (strong pavement)
35.3	7.2	750	-48	-7	6	0.71
36.9	7.5	750	-31	-4	6	0.73
39.2	8.0	750	0	0		
41.7	8.5	750	63	5	8	0.78
43.2	8.8	750	144	8	9	0.82
43.2	8.8	825	356	32	16	2.91
45.1	9.2	750	300	12	10	0.83
45.1	9.2	825	562	38	13	2.30
46.6	9.5	750	418	16	10	0.85
49.1	10.0	750	798	22	10	0.88
52	10.6	750	1959	30	11	0.92
60	12.2	750	7334	54	10	1.01

The results show that for a road that has only busses and they all change from the current legal load of 8 tonnes to 8.8 tonnes with the same tyre pressure of 750kPa then the % increase in damage can be anything from 8% for a strong pavement (SNP = 3.1) to 144% for a weak pavement (SNP= 1.5). For an increase of load to 8.8 tonnes and an increase in tyre pressure to 825kPa then the % increase in damage can be anything from 32% for a strong pavement (SNP = 3.1) to 356% for a weak pavement (SNP= 1.5). This increase in damage for a road with one type of heavy bus and 100% of the heavy vehicles change to 8.8 tonnes is demonstrated in Figure 2 below.

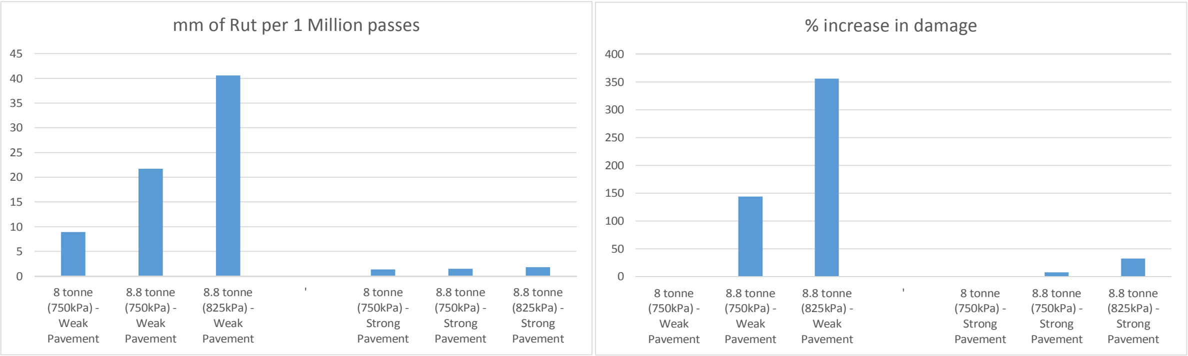


Figure 2: Estimated increase in rutting damage changing from the current legal axle load to 8.8 tonnes on a weak and strong pavement.