IDS

Pavement Cost Impact Assessment from Increased Gross Vehicle Mass on 7 & 8-axle Combination Vehicles

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Quality Assurance Statement	
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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 truck and trailer units.

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 gross vehicle mass of 7 & 8-axle combination vehicles.

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 analysis shows that a rise in pavement wear can be expected across the national road network under the proposed increased gross vehicle mass limits for these vehicles.

The fourth power law was used for determining pavement wear. In addition 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. Outputs from both models are reported

In order to determine the impact of a specific change to the gross mass for a specific combination vehicle, the annual distance travelled (HVKT) by this vehicle is required. The final estimation of HVKT for each vehicle determined by Stimpson and Co. was used in this analysis and the predicted costs are presented for two different scenarios in uptake of the increased mass limits i.e. a *100% uptake* and a *potential uptake*.

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

The predicted cost increase calculated for each of the above scenarios takes into account the efficiency of the heavier combination vehicle by recognising that fewer trips will be required to transport the same amount of freight.

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 costs used to calibrate 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 results of the study for the two uptake scenarios are summarised in Table 0-1 and

Table 0-2 hereafter.

Table 0-1 Predicted cost increase - *100% uptake*

Analysis vehicle	Increased GVM (kg)	km travelled per year (million km)		Dynamic damage exponent			4th Power damage exponent		
				Cost Increase		Difference in cost cf to GML ($M)	Cost Increase		Difference in cost cf to GML ($M)
		SH	LR	SH	LR		SH	LR	
7-Axle Truck & Trailer or B-train (GVM 44,000 kg)									
R12T22	45,000	84.5	32.9	9%	8%	3.32	4%	4%	1.76
B1222		9.1	3.5	9%	8%	0.36	4%	4%	0.19
A223		10.0	3.9	10%	8%	0.32	4%	4%	0.15
					Total	4.00		Total	2.10
8-Axle Truck & Trailer or B-train (GVM 44,000 kg)									
R22T22	46,000	255.8	99.5	26%	22%	29.83	12%	12%	15.64
B1232		58.5	22.7	21%	17%	5.27	9%	9%	2.49
A224		54.7	21.3	21%	17%	3.74	9%	9%	1.76
					Total	38.84		Total	19.90

Table 0-2 Predicted cost increase - *Potential uptake*

Analysis vehicle	Increased GVM (kg)	km travelled per year (million km)		Dynamic damage exponent			4th Power damage exponent		
				Cost Increase		Difference in cost cf to GML ($M)	Cost Increase		Difference in cost cf to GML ($M)
		SH	LR	SH	LR		SH	LR	
7-Axle Truck & Trailer or B-train									
R12T22	45,000	36.9	14.3	9%	8%	1.44	4%	4%	0.77
B1222		0.8	0.3	9%	8%	0.03	4%	4%	0.02
A223		2.2	0.9	13%	8%	0.08	4%	4%	0.03
					Total	1.55		Total	0.82
8-Axle Truck & Trailer or B-train									
R22T22	46,000	55.1	21.4	26%	22%	6.43	12%	12%	3.37
B1232		2.4	0.9	22%	17%	0.23	9%	9%	0.10
A224		4.6	1.8	20%	17%	0.31	9%	9%	0.15
					Total	6.96		Total	3.62

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 and heavier vehicles, designated as High Productivity Motor Vehicles (HPMVs) was aimed at increasing freight productivity across the country.

Changes to the VDAM legislation in 2015 allow increased rear axle loading for high capacity urban buses as defined in Schedule 2 Part C of the amended rule. This has prompted additional proposals from industry for increases in rear axle loading to rigid 2 and 3-axle trucks and buses. IDS was tasked to assess the additional pavement wear-related costs that could be attributed to an increase in the allowable axle groups for these vehicles and reported the results to NZ Transport Agency (NZTA) in February 2016. The report is titled *Pavement Cost Impact Assessment from Increased Axle Loads on 2 and 3-Axle Buses and Trucks*.

Following this assessment NZTA requested IDS to expand this assessment to include combination vehicles with increased gross vehicle mass limits. These vehicles and the range of load increases are summarised in Table 1-1.

Table 1-1 Vehicle combinations

7-axle combinations		8-axle combinations	
44 tonne GVM	Increased GVM	44 tonne GVM	Increased GVM
R12T22	45 tonne	R22T22	46 tonne
B1222		B1232	
A223		A224	

This assessment considers the cost impact from 7 & 8-axle vehicles on both the state highway and local road networks.

It is understood that the proposed load increases described in this report would be applied as an increase to the general mass limits, i.e. there would be no restrictions on access to the entire road network with the exception of weight restricted structures.

This report has been peer reviewed by Dr Ian Greenwood of Greenwood Associates Infrastructure Consultants and this version of the report has been updated in response to the comments.

2. Project objective

The primary objective of this study is to assess the additional pavement wear related costs that could be attributed to an increase in the allowable gross vehicle mass limits on 7 & 8-axle combination vehicles.

3. Report structure

The report outlines the adopted assumptions for the study and contains a summary of the results with a discussion on the findings. A detailed set of results is presented in Appendix A.

Appendix B contains a description of the study methodology and the information used in the evaluation.

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

ii) The reported increases in costs are for the road wear component of the MoT CAM, the road wear component costs have been assessed by the MoT to be approximately 20% of the maintenance and operation costs (background data from MoT discussion paper *What do heavy vehicles pay for and is it enough?*).

iii) In order to determine the impact of a specific change to the gross mass for a specific combination vehicle, the annual distance travelled (HVKT) by this vehicle is required. This allows the impact of the increased axle limits for these vehicles to be assessed. Concurrent work being undertaken by Stimpson & Co. to determine the economic benefits from the increases in freight capacity also required an assessment of the HVKT for each vehicle type. The report authors initially worked with Stimpson & Co. in order to determine an agreed distance estimate for each vehicle type.

   As the analysis progressed it became apparent that the economic benefits were more sensitive to the distances travelled than the overall pavement wear costs. The final estimation of HVKT for each vehicle type has been determined by Stimpson & Co. and reviewed and agreed between Stimpson & Co., MoT, IDS and NZTA. These figures are based on RUC licences purchased between 1 July 2014 and 30 June 2015, the 2014 WIM report and the observations/knowledge of NZTA and MoT personnel. The sensitivity of the HVKT figures was tested as part of this analysis.

iv) As well as providing distances travelled for the *100% uptake* scenario, the Stimpson & Co. work also provides a *potential uptake* for each vehicle type to the new vehicle mass limits over a 40-year study period. The uptake distances in Year 1 were applied to all vehicle.

   The annual distance travelled by each combination vehicle for the state highway (SH) and local road (LR) networks for the two uptake scenarios is shown in Table 4-1 below.

Table 4-1 Annual vehicle distance travelled (million km)

	100% uptake		*Potential uptake - Year 1*	
	SH	**LR**	**SH**	**LR**
7-axle units				
R12T22	87.54	34.04	38.19	14.85
B1222	9.38	3.65	0.80	0.31
A223	10.37	4.03	2.33	0.91
8-axle units				
R22T22	275.45	107.12	59.35	23.08
B1232	63.11	24.54	2.63	1.02
A224	59.17	23.01	4.93	1.92

It is assumed that the 7 and 8-axle combination vehicles are currently travelling at the current limit of 44 tonnes. For this study a range of 25% either side of the *potential uptake* was also assessed. As with the previous studies, no allowance has been made for partially loaded or empty trips. This is implicitly factored in via the HVKT value. Therefore it is feasible that the range in uptake should give a reasonable assessment of increased pavement wear costs.

v) The calculations used to estimate the increase in pavement wear are based on the vehicle combinations being operated at their GVM and individual axle group limits.

vi) The calculations assumed that the HVKT value is with the different vehicle combinations loaded to their GML or increased axle limits. This will produce an upper bound estimate of the costs as not all HVKT are at the maximum limits.

vii) In addition it is assumed that the 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 based on the WIM data; this allows the net freight mass (or payload) 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.

viii) An exponential damage model was used for determining pavement wear. The model was run with two scenarios, firstly with the traditional exponent value of 4 (the "fourth power rule") and secondly using a variable power exponent model. This variable exponent model utilised material test data and pavement rutting information from the Transport Agency Accelerated Pavement Testing facility (CAPTIF) 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).

ix) It is assumed that the current design process will remain unchanged with respect to material types and specifications, pavement analysis and design traffic values. If the mass limits keep increasing over time, a review of the overarching pavement materials, design and construction framework may be required to accommodate the additional loading demands.

4.2 Results

The study results are summarised for the state highway and local road networks in Table 4-2 to Table 4-5 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 GVM and those loaded to the current GML. Results for the *100%* and the *potential uptake* scenarios are shown.

Detailed outputs are presented in Appendix A.

The results are grouped for each vehicle type under consideration. The efficiency of the freight task is as a result of the increase in payload for the higher mass vehicles and is presented as the reduction in distance travelled due to the increase in payload. The kilometres travelled by each vehicle type takes into account the freight task efficiency and are based on the assumed uptake of each vehicle (*100% uptake* and *potential uptake*).

Table 4-2 Predicted Damage Cost Increase (*100% uptake*, Dynamic damage exponent)

			SH					LR				
Analysis vehicle	GVM (kg)	Eff.[1]	Average cost per pass per km ($)	Annual km travelled (Mkm)	Damage Cost per year ($M)	Diff in damage cost ($M)	Increase in cost	Average cost per pass per km ($)	Annual km travelled (Mkm)	Damage Cost per year ($M)	Diff in damage cost ($M)	Increase in cost
7-Axle Truck & Trailer or B-train (GVM 44000 kg)												
R12T22	44000	-	0.14	87.5	12.05	-	-	0.84	34.0	28.45	-	-
	45000	97%	0.16	84.5	13.17	1.12	9%	0.93	32.9	30.66	2.20	8%
B1222	44000	-	0.14	9.4	1.29	-	-	0.84	3.6	3.05	-	-
	45000	97%	0.16	9.1	1.41	0.12	9%	0.93	3.5	3.28	0.24	8%
A223	44000	-	0.10	10.4	1.07	-	-	0.63	4.0	2.53	-	-
	45000	96%	0.12	10.0	1.18	0.11	10%	0.71	3.9	2.74	0.21	8%
8-Axle Truck & Trailer or B-train (GVM 44000 kg)												
R22T22	44000	-	0.14	275.4	37.92	-	-	0.84	107.1	89.52	-	-
	46000	93%	0.19	255.8	47.93	10.01	26%	1.10	99.5	109.34	19.82	22%
B1232	44000	-	0.14	63.1	8.69	-	-	0.84	24.5	20.51	-	-
	46000	93%	0.18	58.5	10.48	1.79	21%	1.05	22.7	23.99	3.48	17%
A224	44000	-	0.10	59.2	6.11	-	-	0.63	23.0	14.42	-	-
	46000	92%	0.13	54.7	7.38	1.27	21%	0.79	21.3	16.89	2.47	17%

1. Reduction in distance travelled due to increase in payload

Table 4-3 Predicted Damage Cost Increase (*Potential uptake*, Dynamic damage exponent)

			SH					LR				
Analysis vehicle	GVM (kg)	Eff.[1]	Average cost per pass per km ($)	Annual km travelled (Mkm)	Damage Cost per year ($M)	Diff in damage cost ($M)	Increase in cost	Average cost per pass per km ($)	Annual km travelled (Mkm)	Damage Cost per year ($M)	Diff in damage cost ($M)	Increase in cost
7-Axle Truck & Trailer or B-train												
R12T22	44000	-	0.14	38.2	5.26	-	-	0.84	14.9	12.41	-	-
	45000	97%	0.16	36.9	5.74	0.48	9%	0.93	14.3	13.37	0.96	8%
B1222	44000	-	0.14	0.8	0.11	-	-	0.84	0.3	0.26	-	-
	45000	97%	0.16	0.8	0.12	0.01	9%	0.93	0.3	0.28	0.02	8%
A223	44000	-	0.10	2.3	0.24	-	-	0.63	0.9	0.57	-	-
	45000	96%	0.12	2.2	0.27	0.03	13%	0.71	0.9	0.62	0.05	8%
8-Axle Truck & Trailer or B-train												
R22T22	44000	-	0.14	59.4	8.17	-	-	0.84	23.1	19.29	-	-
	46000	93%	0.19	55.1	10.33	2.16	26%	1.10	21.4	23.56	4.27	22%
B1232	44000	-	0.14	2.6	0.36	-	-	0.84	1.0	0.86	-	-
	46000	93%	0.18	2.4	0.44	0.08	22%	1.05	0.9	1.00	0.15	17%
A224	44000	-	0.10	4.9	0.51	-	-	0.63	1.9	1.20	-	-
	46000	92%	0.13	4.6	0.61	0.10	20%	0.79	1.8	1.41	0.21	17%

1. Reduction in distance travelled due to increase in payload

Table 4-4 Predicted Damage Cost Increase (*100% uptake*, Damage exponent of 4)

Analysis vehicle	GVM (kg)	Eff.[1]	SH					LR				
			Average cost per pass per km ($)	Annual km travelled (Mkm)	Damage Cost per year ($M)	Diff in damage cost ($M)	Increase in cost	Average cost per pass per km ($)	Annual km travelled (Mkm)	Damage Cost per year ($M)	Diff in damage cost ($M)	Increase in cost
7-Axle Truck & Trailer or B-train (GVM 44000 kg)												
R12T22	44000	-	0.14	87.5	12.05	-	-	0.84	34.0	28.45	-	-
	45000	97%	0.15	84.5	12.58	0.52	4%	0.90	32.9	29.69	1.24	4%
B1222	44000	-	0.14	9.4	1.29	-	-	0.84	3.6	3.05	-	-
	45000	97%	0.15	9.1	1.35	0.06	4%	0.90	3.5	3.18	0.13	4%
A223	44000	-	0.10	10.4	1.07	-	-	0.63	4.0	2.53	-	-
	45000	96%	0.11	10.0	1.12	0.05	4%	0.68	3.9	2.64	0.11	4%
8-Axle Truck & Trailer or B-train (GVM 44000 kg)												
R22T22	44000	-	0.14	275.4	37.92	-	-	0.84	107.1	89.52	-	-
	46000	93%	0.17	255.8	42.58	4.65	12%	1.01	99.5	100.51	10.99	12%
B1232	44000	-	0.14	63.1	8.69	-	-	0.84	24.5	20.51	-	-
	46000	93%	0.16	58.5	9.43	0.74	9%	0.98	22.7	22.26	1.75	9%
A224	44000	-	0.10	59.2	6.11	-	-	0.63	23.0	14.42	-	-
	46000	92%	0.12	54.7	6.63	0.52	9%	0.74	21.3	15.66	1.24	9%

1. Reduction in distance travelled due to increase in payload

Table 4-5 Predicted Damage Cost Increase (*Potential uptake*, Damage exponent of 4)

Analysis vehicle	GVM (kg)	Eff.[1]	SH					LR				
			Average cost per pass per km ($)	Annual km travelled (Mkm)	Damage Cost per year ($M)	Diff in damage cost ($M)	Increase in cost	Average cost per pass per km ($)	Annual km travelled (Mkm)	Damage Cost per year ($M)	Diff in damage cost ($M)	Increase in cost
7-Axle Truck & Trailer or B-train (Year 1 uptake)												
R12T22	44000	-	0.14	38.2	5.26	-	-	0.84	14.9	12.41	-	-
	45000	97%	0.15	36.9	5.49	0.23	4%	0.90	14.3	12.95	0.54	4%
B1222	44000	-	0.14	0.8	0.11	-	-	0.84	0.3	0.26	-	-
	45000	97%	0.15	0.8	0.11	0.00	4%	0.90	0.3	0.27	0.01	4%
A223	44000	-	0.10	2.3	0.24	-	-	0.63	0.9	0.57	-	-
	45000	96%	0.11	2.2	0.25	0.01	4%	0.68	0.9	0.59	0.02	4%
8-Axle Truck & Trailer or B-train (Year 1 uptake)												
R22T22	44000	-	0.14	59.4	8.17	-	-	0.84	23.1	19.29	-	-
	46000	93%	0.17	55.1	9.17	1.00	12%	1.01	21.4	21.66	2.37	12%
B1232	44000	-	0.14	2.6	0.36	-	-	0.84	1.0	0.86	-	-
	46000	93%	0.16	2.4	0.39	0.03	9%	0.98	0.9	0.93	0.07	9%
A224	44000	-	0.10	4.9	0.51	-	-	0.63	1.9	1.20	-	-
	46000	92%	0.12	4.6	0.55	0.04	9%	0.74	1.8	1.30	0.10	9%

1. Reduction in distance travelled due to increase in payload

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:

i) 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.

ii) 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 settle down after a year or two with the future deterioration occurring at an acceptable rate. 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.

iii) 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. In addition, the volume of freight being transported on HPMV permits is increasing rapidly. 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 ability of the current body of knowledge on pavement wear to predict the performance of existing pavements that are subjected to significant (>10%) increases in either individual axle or axle group loads is less certain. This uncertainty in the impact means that the estimated financial costs for the upper band of load increases are less certain than for the lower levels of load increases.

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.

This study also assessed the cost impact for a range in the potential uptake in distance travelled. Results for the dynamic damage exponent are presented in Table 4-6 below.

Table 4-6 Predicted Damage Cost Increase (± 25% of potential uptake)

Analysis vehicle	Increased GVM (kg)	km travelled per year (million km)			Dynamic damage exponent: Difference in cost cf to GML ($M)			4th Power damage exponent: Difference in cost cf to GML ($M)		
		- 25%	Potential uptake	+ 25%	- 25%	Potential uptake	+ 25%	- 25%	Potential uptake	+ 25%
7-Axle Truck & Trailer or B-train (GVM 44,000 kg) (Year 1 uptake)										
R12T22	45,000	28.8	51.2	80.0	0.81	1.44	2.26	0.43	0.77	1.20
B1222		0.6	1.1	1.7	0.02	0.03	0.05	0.01	0.02	0.03
A223		1.8	3.1	4.9	0.04	0.08	0.12	0.02	0.03	0.05
				Total	*0.87*	*1.55*	*2.43*	*0.46*	*0.82*	*1.28*
8-Axle Truck & Trailer or B-train (GVM 44,000 kg) (Year 1 uptake)										
R22T22	46,000	43.1	76.6	119.6	3.61	6.43	10.04	1.90	3.37	5.27
B1232		1.9	3.4	5.3	0.13	0.23	0.34	0.06	0.10	0.16
A224		3.6	6.3	9.9	0.18	0.31	0.48	0.08	0.15	0.23
				Total	*3.92*	*6.96*	*10.86*	*2.04*	*3.62*	*5.66*

A 25% increase in uptake to the new limits over and above the potential uptake, will cause a disproportionate increase in damage costs of between 48% and 75% across the entire road network. Similarly for a 25% decrease in uptake, the damage costs across the network will reduce by between 29% and 44%.

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 in Table 4-7 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 *100%* of the fleet to the increased mass limits.

The analysis shows that the damage cost more than 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.

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.

Table 4-7 Damage Cost Sensitivity

Analysis vehicle	Increased GVM (kg)	Assumed network distribution			Revised distribution		
		Cost Increase ($M)		Total cost increase ($M)	Cost Increase ($M)		Total cost increase ($M)
		SH	LR		SH	LR	
7-Axle Truck & Trailer or B-train (GVM 44,000 kg)							
R12T22	45,000	1.12	2.20	3.32	2.27	4.41	6.68
B1222		0.12	0.24	0.36	0.24	0.47	0.72
A223		0.11	0.21	0.32	0.22	0.43	0.65
				4.00		Total	8.04
						Increase	*101%*
8-Axle Truck & Trailer or B-train (GVM 44,000 kg)							
R22T22	46,000	10.01	19.82	29.83	20.18	39.30	59.48
B1232		1.79	3.48	5.27	3.65	7.00	10.65
A224		1.27	2.47	3.74	2.59	4.96	7.55
				38.84		Total	77.68
						Increase	*100%*

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 of 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

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 analysis shows that a rise in pavement wear can be expected across the national road network under the proposed increased gross vehicle mass limits for these vehicles.

The predicted costs are presented for two different scenarios in uptake of the increased mass limits i.e. a *100% uptake* and a *potential uptake* 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 costs used to calibrate 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 results for the two uptake scenarios are summarised in Table 5-1 and Table 5-2.

Table 5-1 Predicted cost increase (*100% uptake*)

Analysis vehicle	Increased GVM (kg)	km travelled per year (million km) SH	km travelled per year (million km) LR	Dynamic damage exponent Cost Increase SH	Dynamic damage exponent Cost Increase LR	Dynamic damage exponent Difference in cost cf to GML ($M)	4th Power damage exponent Cost Increase SH	4th Power damage exponent Cost Increase LR	4th Power damage exponent Difference in cost cf to GML ($M)
7-Axle Truck & Trailer or B-train (GVM 44,000 kg)									
R12T22	45,000	84.5	32.9	9%	8%	3.32	4%	4%	1.76
B1222		9.1	3.5	9%	8%	0.36	4%	4%	0.19
A223		10.0	3.9	10%	8%	0.32	4%	4%	0.15
					Total	4.00		Total	2.10
8-Axle Truck & Trailer or B-train (GVM 44,000 kg)									
R22T22	46,000	255.8	99.5	26%	22%	29.83	12%	12%	15.64
B1232		58.5	22.7	21%	17%	5.27	9%	9%	2.49
A224		54.7	21.3	21%	17%	3.74	9%	9%	1.76
					Total	38.84		Total	19.90

Table 5-2 Predicted cost increase (*Potential uptake*)

Analysis vehicle	Increased GVM (kg)	km travelled per year (million km) SH	km travelled per year (million km) LR	Dynamic damage exponent Cost Increase SH	Dynamic damage exponent Cost Increase LR	Dynamic damage exponent Difference in cost cf to GML ($M)	4th Power damage exponent Cost Increase SH	4th Power damage exponent Cost Increase LR	4th Power damage exponent Difference in cost cf to GML ($M)
7-Axle Truck & Trailer or B-train									
R12T22	45,000	36.9	14.3	9%	8%	1.44	4%	4%	0.77
B1222		0.8	0.3	9%	8%	0.03	4%	4%	0.02
A223		2.2	0.9	13%	8%	0.08	4%	4%	0.03
					Total	1.55		Total	0.82
8-Axle Truck & Trailer or B-train									
R22T22	46,000	55.1	21.4	26%	22%	6.43	12%	12%	3.37
B1232		2.4	0.9	22%	17%	0.23	9%	9%	0.10
A224		4.6	1.8	20%	17%	0.31	9%	9%	0.15
					Total	6.96		Total	3.62

6. References

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APPENDIX A: Detailed results

Detailed results of the analysis are presented in the tables below.

Results for the dynamic damage exponent are presented in Table A-1 and Table A-2, and the results for a damage exponent of 4 are presented in Table A-3 to Table A-4. Results for both the 100% uptake and the potential uptake are shown.

Table A-1 State Highways & Local Roads, *100% uptake*, Dynamic damage exponent

NATIONAL STATE HIGHWAYS: 100% UPTAKE — Dynamic damage exponent

Vehicle	Current or New[1]	GVM (kg)	Eff.[2]	Extremely weak	Very weak	Weak	Average	Strong	Very strong	Average cost per pass per km ($)	km of travel per year (million km)	Predicted Damage cost per year ($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
			Damage exponent	9.0	5.6	3.5	1.9	1.1	1.1						
			Expected rem. life MESA	0.031	0.265	0.728	7.271	21.315	133.156						
			Length (km)	24	32	69	2229	1579	4142						
			Network length	0%	0%	1%	28%	20%	51%						
				Cost per km per vehicle pass ($)											
7-Axle Truck & Trailer or B-train															
R12T22	Current	44000	-	25.76	3.01	1.10	0.11	0.04	0.01	0.14	87.54	12.05	-	-	-
	New	45000	97%	30.77	3.36	1.18	0.11	0.04	0.01	0.16	84.55	13.17	1.12	0.02	9%
B1222	Current	44000	-	25.76	3.01	1.10	0.11	0.04	0.01	0.14	9.38	1.29	-	-	-
	New	45000	97%	30.77	3.36	1.18	0.11	0.04	0.01	0.16	9.06	1.41	0.12	0.02	9%
A223	Current	44000	-	19.32	2.26	0.82	0.08	0.03	0.00	0.10	10.37	1.07	-	-	-
	New	45000	96%	23.53	2.54	0.88	0.09	0.03	0.00	0.12	9.99	1.18	0.11	0.01	10%
8-Axle Truck & Trailer or B-train															
R22T22	Current	44000	-	25.76	3.01	1.10	0.11	0.04	0.01	0.14	275.45	37.92	-	-	-
	New	46000	93%	39.72	3.94	1.30	0.12	0.04	0.01	0.19	255.82	47.93	10.01	0.05	26%
B1232	Current	44000	-	25.76	3.01	1.10	0.11	0.04	0.01	0.14	63.11	8.69	-	-	-
	New	46000	93%	37.46	3.78	1.26	0.12	0.04	0.01	0.18	58.48	10.48	1.79	0.04	21%
A224	Current	44000	-	19.32	2.26	0.82	0.08	0.03	0.00	0.10	59.17	6.11	-	-	-
	New	46000	92%	28.22	2.84	0.95	0.09	0.03	0.00	0.13	54.71	7.38	1.27	0.03	21%

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

LOCAL ROADS: 100% UPTAKE — Dynamic damage exponent

Vehicle	Current or New[1]	GVM (kg)	Eff.[2]	Extremely weak	Very weak	Weak	Average	Strong	Very strong	Average cost per pass per km ($)	km of travel per year (million km)	Predicted Damage cost per year ($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
			Damage exponent	9.0	5.6	3.5	1.9	1.9	1.1						
			Expected rem. life MESA	0.010	0.088	0.235	2.002	6.782	24.174						
			Length (km)	366	1079	2803	49862	14888	14279						
			Network length	0%	1%	3%	60%	18%	17%						
				Cost per km per vehicle pass ($)											
7-Axle Truck & Trailer or B-train															
R12T22	Current	44000	-	76.66	9.10	3.41	0.40	0.12	0.03	0.84	34.04	28.45	-	-	-
	New	45000	97%	91.56	10.15	3.64	0.41	0.12	0.03	0.93	32.88	30.66	2.20	0.09	8%
B1222	Current	44000	-	76.66	9.10	3.41	0.40	0.12	0.03	0.84	3.65	3.05	-	-	-
	New	45000	97%	91.56	10.15	3.64	0.41	0.12	0.03	0.93	3.52	3.28	0.24	0.09	8%
A223	Current	44000	-	57.49	6.82	2.55	0.30	0.09	0.02	0.63	4.03	2.53	-	-	-
	New	45000	96%	70.01	7.66	2.74	0.31	0.09	0.03	0.71	3.88	2.74	0.21	0.08	8%
8-Axle Truck & Trailer or B-train															
R22T22	Current	44000	-	76.66	9.10	3.41	0.40	0.12	0.03	0.84	107.12	89.52	-	-	-
	New	46000	93%	118.18	11.90	4.02	0.44	0.12	0.03	1.10	99.49	109.34	19.82	0.24	22%
B1232	Current	44000	-	76.66	9.10	3.41	0.40	0.12	0.03	0.84	24.54	20.51	-	-	-
	New	46000	93%	111.45	11.41	3.91	0.43	0.12	0.03	1.05	22.74	23.99	3.48	0.20	17%
A224	Current	44000	-	57.49	6.82	2.55	0.30	0.09	0.02	0.63	23.01	14.42	-	-	-
	New	46000	92%	83.98	8.59	2.94	0.32	0.09	0.03	0.79	21.28	16.89	2.47	0.15	17%

Table A-2 State Highways & Local Roads, *Potential uptake*, Dynamic damage exponent

NATIONAL STATE HIGHWAYS: POTENTIAL UPTAKE — Dynamic damage exponent

Vehicle	Current or New[1]	GVM (kg)	Eff.[2]	Extremely weak	Very weak	Weak	Average	Strong	Very strong	Average cost per pass per km ($)	km of travel per year (million km)	Predicted Damage cost per year ($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
			Damage exponent	9.0	5.6	3.5	1.9	1.1	1.1						
			Expected rem. life MESA	0.031	0.265	0.728	7.271	21.315	133.156						
			Length (km)	24	32	69	2229	1579	4142						
			Network length	0%	0%	1%	28%	20%	51%						
				Cost per km per vehicle pass ($)											
7-Axle Truck & Trailer or B-train															
R12T22	Current	44000	-	25.76	3.01	1.10	0.11	0.04	0.01	0.14	38.19	5.26	-	-	-
	New	45000	97%	30.77	3.36	1.18	0.11	0.04	0.01	0.16	36.88	5.74	0.48	0.02	9%
B1222	Current	44000	-	25.76	3.01	1.10	0.11	0.04	0.01	0.14	0.80	0.11	-	-	-
	New	45000	97%	30.77	3.36	1.18	0.11	0.04	0.01	0.16	0.77	0.12	0.01	0.02	9%
A223	Current	44000	-	19.32	2.26	0.82	0.08	0.03	0.00	0.10	2.33	0.24	-	-	-
	New	45000	96%	23.53	2.54	0.88	0.09	0.03	0.00	0.12	2.25	0.27	0.03	0.01	13%
8-Axle Truck & Trailer or B-train															
R22T22	Current	44000	-	25.76	3.01	1.10	0.11	0.04	0.01	0.14	59.35	8.17	-	-	-
	New	46000	93%	39.72	3.94	1.30	0.12	0.04	0.01	0.19	55.12	10.33	2.16	0.05	26%
B1232	Current	44000	-	25.76	3.01	1.10	0.11	0.04	0.01	0.14	2.63	0.36	-	-	-
	New	46000	93%	37.46	3.78	1.26	0.12	0.04	0.01	0.18	2.44	0.44	0.08	0.04	22%
A224	Current	44000	-	19.32	2.26	0.82	0.08	0.03	0.00	0.10	4.93	0.51	-	-	-
	New	46000	92%	28.22	2.84	0.95	0.09	0.03	0.00	0.13	4.56	0.61	0.10	0.03	20%

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

LOCAL ROADS: POTENTIAL UPTAKE — Dynamic damage exponent

Vehicle	Current or New[1]	GVM (kg)	Eff.[2]	Extremely weak	Very weak	Weak	Average	Strong	Very strong	Average cost per pass per km ($)	km of travel per year (million km)	Predicted Damage cost per year ($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
			Damage exponent	9.0	5.6	3.5	1.9	1.9	1.1						
			Expected rem. life MESA	0.010	0.088	0.235	2.002	6.782	24.174						
			Length (km)	366	1079	2803	49862	14888	14279						
			Network length	0%	1%	3%	60%	18%	17%						
				Cost per km per vehicle pass ($)											
7-Axle Truck & Trailer or B-train															
R12T22	Current	44000	-	76.66	9.10	3.41	0.40	0.12	0.03	0.84	14.85	12.41	-	-	-
	New	45000	97%	91.56	10.15	3.64	0.41	0.12	0.03	0.93	14.34	13.37	0.96	0.09	8%
B1222	Current	44000	-	76.66	9.10	3.41	0.40	0.12	0.03	0.84	0.31	0.26	-	-	-
	New	45000	97%	91.56	10.15	3.64	0.41	0.12	0.03	0.93	0.30	0.28	0.02	0.09	8%
A223	Current	44000	-	57.49	6.82	2.55	0.30	0.09	0.02	0.63	0.91	0.57	-	-	-
	New	45000	96%	70.01	7.66	2.74	0.31	0.09	0.03	0.71	0.87	0.62	0.05	0.08	8%
8-Axle Truck & Trailer or B-train															
R22T22	Current	44000	-	76.66	9.10	3.41	0.40	0.12	0.03	0.84	23.08	19.29	-	-	-
	New	46000	93%	118.18	11.90	4.02	0.44	0.12	0.03	1.10	21.44	23.56	4.27	0.24	22%
B1232	Current	44000	-	76.66	9.10	3.41	0.40	0.12	0.03	0.84	1.02	0.86	-	-	-
	New	46000	93%	111.45	11.41	3.91	0.43	0.12	0.03	1.05	0.95	1.00	0.15	0.20	17%
A224	Current	44000	-	57.49	6.82	2.55	0.30	0.09	0.02	0.63	1.92	1.20	-	-	-
	New	46000	92%	83.98	8.59	2.94	0.32	0.09	0.03	0.79	1.77	1.41	0.21	0.15	17%

Table A-3 State Highways, *100% uptake*, damage exponent of 4

NATIONAL STATE HIGHWAYS: 100% UPTAKE — 4th Power damage exponent

Vehicle	Current or New[1]	GVM (kg)	Eff.[2]	Extremely weak	Very weak	Weak	Average	Strong	Very strong	Average cost per pass per km ($)	km of travel per year (million km)	Predicted Damage cost per year ($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
			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 ($)											
7-Axle Truck & Trailer or B-train															
R12T22	Current	44000	-	25.76	3.01	1.10	0.11	0.04	0.01	0.14	87.54	12.05	-	-	-
	New	45000	97%	27.84	3.26	1.19	0.12	0.04	0.01	0.15	84.55	12.58	0.52	0.01	4%
B1222	Current	44000	-	25.76	3.01	1.10	0.11	0.04	0.01	0.14	9.38	1.29	-	-	-
	New	45000	97%	27.84	3.26	1.19	0.12	0.04	0.01	0.15	9.06	1.35	0.06	0.01	4%
A223	Current	44000	-	19.32	2.26	0.82	0.08	0.03	0.00	0.10	10.37	1.07	-	-	-
	New	45000	96%	20.93	2.45	0.89	0.09	0.03	0.00	0.11	9.99	1.12	0.05	0.01	4%
8-Axle Truck & Trailer or B-train															
R22T22	Current	44000	-	25.76	3.01	1.10	0.11	0.04	0.01	0.14	275.45	37.92	-	-	-
	New	46000	93%	31.15	3.64	1.33	0.13	0.05	0.01	0.17	255.82	42.58	4.65	0.03	12%
B1232	Current	44000	-	25.76	3.01	1.10	0.11	0.04	0.01	0.14	63.11	8.69	-	-	-
	New	46000	93%	30.18	3.53	1.29	0.13	0.04	0.01	0.16	58.48	9.43	0.74	0.02	9%
A224	Current	44000	-	19.32	2.26	0.82	0.08	0.03	0.00	0.10	59.17	6.11	-	-	-
	New	46000	92%	22.69	2.65	0.97	0.10	0.03	0.01	0.12	54.71	6.63	0.52	0.02	9%

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

LOCAL ROADS: 100% UPTAKE — 4th Power damage exponent

Vehicle	Current or New[1]	GVM (kg)	Eff.[2]	Extremely weak	Very weak	Weak	Average	Strong	Very strong	Average cost per pass per km ($)	km of travel per year (million km)	Predicted Damage cost per year ($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
			Damage exponent	9.0	5.6	3.5	1.9	1.9	1.1						
			Expected rem. life MESA	0.010	0.088	0.235	2.002	6.782	24.174						
			Length (km)	366	1079	2803	49862	14888	14279						
			Network length	0%	1%	3%	60%	18%	17%						
				Cost per km per vehicle pass ($)											
7-Axle Truck & Trailer or B-train															
R12T22	Current	44000	-	76.66	9.10	3.41	0.40	0.12	0.03	0.84	34.04	28.45	-	-	-
	New	45000	97%	82.83	9.83	3.68	0.43	0.13	0.04	0.90	32.88	29.69	1.24	0.06	4%
B1222	Current	44000	-	76.66	9.10	3.41	0.40	0.12	0.03	0.84	3.65	3.05	-	-	-
	New	45000	97%	82.83	9.83	3.68	0.43	0.13	0.04	0.90	3.52	3.18	0.13	0.06	4%
A223	Current	44000	-	57.49	6.82	2.55	0.30	0.09	0.02	0.63	4.03	2.53	-	-	-
	New	45000	96%	62.26	7.39	2.77	0.32	0.10	0.03	0.68	3.88	2.64	0.11	0.05	4%
8-Axle Truck & Trailer or B-train															
R22T22	Current	44000	-	76.66	9.10	3.41	0.40	0.12	0.03	0.84	107.12	89.52	-	-	-
	New	46000	93%	92.67	11.00	4.12	0.48	0.14	0.04	1.01	99.49	100.51	10.99	0.16	12%
B1232	Current	44000	-	76.66	9.10	3.41	0.40	0.12	0.03	0.84	24.54	20.51	-	-	-
	New	46000	93%	89.79	10.66	3.99	0.47	0.14	0.04	0.98	22.74	22.26	1.75	0.13	9%
A224	Current	44000	-	57.49	6.82	2.55	0.30	0.09	0.02	0.63	23.01	14.42	-	-	-
	New	46000	92%	67.51	8.01	3.00	0.35	0.10	0.03	0.74	21.28	15.66	1.24	0.10	9%

Table A-4 State Highways, *Potential uptake*, damage exponent of 4

NATIONAL STATE HIGHWAYS: POTENTIAL UPTAKE — 4th Power damage exponent

Vehicle	Current or New[1]	GVM (kg)	Eff.[2]	Extremely weak	Very weak	Weak	Average	Strong	Very strong	Average cost per pass per km ($)	km of travel per year (million km)	Predicted Damage cost per year ($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
			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 ($)											
7-Axle Truck & Trailer or B-train															
R12T22	Current	44000	-	25.76	3.01	1.10	0.11	0.04	0.01	0.14	38.19	5.26	-	-	-
	New	45000	97%	27.84	3.26	1.19	0.12	0.04	0.01	0.15	36.88	5.49	0.23	0.01	4%
B1222	Current	44000	-	25.76	3.01	1.10	0.11	0.04	0.01	0.14	0.80	0.11	-	-	-
	New	45000	97%	27.84	3.26	1.19	0.12	0.04	0.01	0.15	0.77	0.11	0.00	0.01	4%
A223	Current	44000	-	19.32	2.26	0.82	0.08	0.03	0.00	0.10	2.33	0.24	-	-	-
	New	45000	96%	20.93	2.45	0.89	0.09	0.03	0.00	0.11	2.25	0.25	0.01	0.01	4%
8-Axle Truck & Trailer or B-train															
R22T22	Current	44000	-	25.76	3.01	1.10	0.11	0.04	0.01	0.14	59.35	8.17	-	-	-
	New	46000	93%	31.15	3.64	1.33	0.13	0.05	0.01	0.17	55.12	9.17	1.00	0.03	12%
B1232	Current	44000	-	25.76	3.01	1.10	0.11	0.04	0.01	0.14	2.63	0.36	-	-	-
	New	46000	93%	30.18	3.53	1.29	0.13	0.04	0.01	0.16	2.44	0.39	0.03	0.02	9%
A224	Current	44000	-	19.32	2.26	0.82	0.08	0.03	0.00	0.10	4.93	0.51	-	-	-
	New	46000	92%	22.69	2.65	0.97	0.10	0.03	0.01	0.12	4.56	0.55	0.04	0.02	9%

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

LOCAL ROADS: POTENTIAL UPTAKE — 4th Power damage exponent

Vehicle	Current or New[1]	GVM (kg)	Eff.[2]	Extremely weak	Very weak	Weak	Average	Strong	Very strong	Average cost per pass per km ($)	km of travel per year (million km)	Predicted Damage cost per year ($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
			Damage exponent	9.0	5.6	3.5	1.9	1.9	1.1						
			Expected rem. life MESA	0.010	0.088	0.235	2.002	6.782	24.174						
			Length (km)	366	1079	2803	49862	14888	14279						
			Network length	0%	1%	3%	60%	18%	17%						
				Cost per km per vehicle pass ($)											
7-Axle Truck & Trailer or B-train															
R12T22	Current	44000	-	76.66	9.10	3.41	0.40	0.12	0.03	0.84	14.85	12.41	-	-	-
	New	45000	97%	82.83	9.83	3.68	0.43	0.13	0.04	0.90	14.34	12.95	0.54	0.06	4%
B1222	Current	44000	-	76.66	9.10	3.41	0.40	0.12	0.03	0.84	0.31	0.26	-	-	-
	New	45000	97%	82.83	9.83	3.68	0.43	0.13	0.04	0.90	0.30	0.27	0.01	0.06	4%
A223	Current	44000	-	57.49	6.82	2.55	0.30	0.09	0.02	0.63	0.91	0.57	-	-	-
	New	45000	96%	62.26	7.39	2.77	0.32	0.10	0.03	0.68	0.87	0.59	0.02	0.05	4%
8-Axle Truck & Trailer or B-train															
R22T22	Current	44000	-	76.66	9.10	3.41	0.40	0.12	0.03	0.84	23.08	19.29	-	-	-
	New	46000	93%	92.67	11.00	4.12	0.48	0.14	0.04	1.01	21.44	21.66	2.37	0.16	12%
B1232	Current	44000	-	76.66	9.10	3.41	0.40	0.12	0.03	0.84	1.02	0.86	-	-	-
	New	46000	93%	89.79	10.66	3.99	0.47	0.14	0.04	0.98	0.95	0.93	0.07	0.13	9%
A224	Current	44000	-	57.49	6.82	2.55	0.30	0.09	0.02	0.63	1.92	1.20	-	-	-
	New	46000	92%	67.51	8.01	3.00	0.35	0.10	0.03	0.74	1.77	1.30	0.10	0.10	9%

APPENDIX B: 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 1-0-1 Vehicle kilometers travelled split

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

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

[2] Data supplied by MoT

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

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.

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 as this was deemed to be the best available dataset. It is observed that the SDC network has approximately 60% in the average strength/remaining life category so this could be considered an "average" network. A sensitivity analysis on the percentage of the network with low strength showed that doubling the length of the low strength network had a measurable impact on the cost.

Table 1-0-2 State Highway Pavement Classes

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

Table 1-0-3 Local Road Pavement Classes (Southland DC Network)

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

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.

This approach for determining the additional cost was adopted on the basis that an increase in loading would create a real cost to the roading authorities due to increased rates of deterioration in the short term, rather than adopting a whole of life approach. It could be argued that it is unfair to allocate the strengthening cost to the future traffic that will consume the remaining pavement life, however if a whole of life approach was adopted, the future pavement design would not reflect the increase in vehicle mass as the pavement thickness is driven by subgrade strength and a fleet averaged ESA/HCV factor and would therefore show very little or no increased future cost.

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).

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 gross mass for a specific combination vehicle, 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.