IDS

Pavement Cost Impact Assessment from Increased Vehicle Mass Limits - Calculation Sheet Guide

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IDS - Infrastructure Decision Support

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http://www.ids.org.nz/

Quality Assurance Statement	
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Contents

1. Introduction

1.1 Background

IDS has been engaged by the NZ Transport Agency 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, and the gross vehicle mass of 7, 8 and 9-axle combination vehicles. The study quantified the impact on pavement wear in terms of the relative cost increase associated with pavement maintenance resulting from different load scenarios for the different vehicle types.

The results from this analysis and the study methodology were summarised in two separate IDS reports that accompanied the release of the draft Land Transport Rule: Vehicle Dimensions and Mass (2016) in July 2016. These reports contained summary tables from the cost calculation sheet that was developed by IDS for this analysis.

NZTA intends to make the methodology for the calculation of the additional maintenance costs, available to a wider audience. This will enable roading authorities and freight operators to predict potential cost impacts from increased axle loads on their networks or particular route.

1.2 Purpose

The purpose of this document is to outline the process for the calculation of the additional maintenance costs, and to guide the user through the calculation sheet and the selection of the required inputs.

The cost calculation sheet enables the user to define an analysis vehicle and apply it to a road network or particular route with specific pavement strength characteristics.

1.3 Disclaimer

The cost calculation sheet is based on the methodology developed by IDS for assessing the additional maintenance wear-related costs that could be attributed to an increase in the allowable axle group loads on heavy vehicles. The calculation sheet has been prepared by IDS on the specific instructions of NZTA and it should be used for the purpose for which it is intended in accordance with the original agreed scope of work. The calculations and formulae in the calculation sheet are not protected and can be changed by the user.

IDS accepts no liability or responsibility whatsoever for any loss or damage suffered by the recipient arising out of, or in connection with, the use or misuse of the calculation sheet and guide.

While all reasonable means have been used to ensure that the transfer medium and its contents are free of computer viruses, IDS cannot be held responsible for any loss or damage that may result from their presence.

Should the user be in any doubt as to the applicability of this guide and cost calculation sheet as described herein, it is essential that you discuss these issues with the authors before proceeding with any work based on this document.

1.4 Report structure

The report serves as a guide for use with the cost calculation sheet. It presents an overview of the cost calculation methodology and contains several screen shots from the calculation sheet for the user to follow.

This guide is accompanied by an electronic copy of the Excel spreadsheet (*IDS Public Cost Calculator_v1.xlsx*).

2. Calculation of additional maintenance costs

2.1 Overview

This spreadsheet calculates the additional maintenance costs on a roading network or a particular route caused by an increase in axle loads by one heavy vehicle type.

Assessment Philosophy

The spreadsheet has two parts, (1) a normalisation of the road wear component of the roading authority maintenance costs and (2) calculation of the increase in road wear and cost associated with the change in vehicle configuration.

Figure 2-1 shows an overview of the spreadsheet. The different sections are described hereafter.

Input cells are shaded in green. The calculations and formulae in the spreadsheet are not protected which allows the user to make changes as required.

EXTRA COST PER VEHICLE FROM INCREASE IN MASS LIMITS

Axle group	Standard Axle Group Loads kN	Standard Axle Group Loads kg	GML Limits (kg)	HPMV Limits (kg)
SAST	53	5403	5400	6000
SADT	80	8155	8200	8800
TADT	135	13761	13500	15000
TRDT	181	18451	16000	18000
SAST(SS)	71	7238	10000	11000
QADT	221	22528	18000	22000
TAST	106	10805	10800	10800
NU	0	0	0	0

FULLY LOADED

HPMV NETWORK						
Pavement Class	1	2	3	4	5	6
Strength (in terms of remaining life)	extremely weak	very weak	weak	average	strong	v. strong
Exponent (axle loads > reference load)	9.05	5.65	3.49	1.90	1.10	1.05
Exponent (axle loads < reference load)	3.34	1.87	1.03	1.00	1.00	1.00
Expected life ESAs (MESA) for each pavement class	0.0311	0.2654	0.7279	7.2710	21.3151	133.1557
Pavement Life Multiplier Factor (can leave as 1.0)	1.0000					
Length of road in this stength and life catergory	24	32	69	2,229	1,579	4,142
% of Network Length	0.3%	0.4%	0.9%	27.6%	19.6%	51.3%
Avg Pavement Mntce Cost (adjusted to match total spend) $/km	$ 211,864	$ 211,864	$ 211,864	$ 211,864	$ 211,864	$ 211,864
Cost $/km/ESA	$ 6.82	$ 0.80	$ 0.29	$ 0.03	$ 0.01	$ 0.00
Lives (MESA) before patching or pavement renewal	0.031	0.265	0.728	7.271	21.315	133.156

HVKT per year related to the $ spend on maintenance	1,515,298,390				
Average ESA per all HCVs from WIM using 4th power	1.67				
Austroads Reference Load Adjustment Factor	1.000				
Total ESAs per year	2.531E+09				The target cost is
Calculated Total $ spend per year	$ 87,101,789	Compare this with actual spend per year		87,101,789	Input the $ sper
Avg ESA for all HCVs based on values given in this spreadsheet	1.67		Calc Total Spend	$ 87,101,789	1.059
Cost per km per average HCV	0.057 $/km		Difference	$ 0	
Target cost per km per average HCV network	0.057 $/km				
	0.057 $/km				

ANALYSIS VEHICLE

	Axle groups ->	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	
	R12T22	SAST	TADT	TADT	TADT	NU	NU	Total (kg)
Current vehicle	Ref load (kg)	5,403	13,761	13,761	13,761	0	0	
	GVM (kg)	5,400	13,800	12,400	12,400	0	0	44,000
							Tare	15,763
							Payload	28,237
Case 1	Inc. load (kg)	5,400	14,200	12,700	12,700	0	0	45,000
							Load	*1,000*
							Increase	*2%*
							Payload	29,237
							Efficiency	97%

	1	2	3	4	5	6
ESA	3.44	3.66	3.81	3.81	3.80	3.80
$/km/1 veh pass	$ 23.45	$ 2.92	$ 1.11	$ 0.11	$ 0.04	$ 0.01
Total $ / 1 veh pass	$ 555.87	$ 92.61	$ 76.57	$ 247.28	$ 59.71	$ 25.07
Average $/km/1 veh pass			0.13			
ESA	3.86	3.91	3.96	3.91	3.88	3.88
$/km/1 veh pass	$ 26.31	$ 3.12	$ 1.15	$ 0.11	$ 0.04	$ 0.01
Total $ / 1 veh pass	$ 623.81	$ 99.01	$ 79.61	$ 253.75	$ 60.90	$ 25.56
Average $/km/1 veh pass			0.14			
Extra $/km/1 veh pass			0.01			

Current loaded heavy veh km per year	87,541,213
% uptake	100
Current loaded veh km per year that will change	87,541,213
New veh km per year incl efficiency	84,547,020
Extra $ pavement wear	$ 503,454

Figure 2-1 Cost calculation sheet overview

2.2 Pavement classes with associated lives and length

The road network is divided into 6 classes based expected lives from very short to very long as indicated in Figure 2-2. This assessment should pick up potential small areas that will result in the need of a small maintenance patch. The %, length or area of road network or route needs to primarily relate to the expected life in terms of millions of equivalent standard axles MESAs before a patch repair or pavement renewal is required.

Pavement Class	1	2	3	4	5	6
Strength (in terms of remaining life)	extremely weak	very weak	weak	average	strong	v. strong
Exponent (axle loads > reference load)	9.05	5.65	3.49	1.90	1.10	1.05
Exponent (axle loads < reference load)	3.34	1.87	1.03	1.00	1.00	1.00
Expected life ESAs (MESA) for each pavement class	0.0311	0.2654	0.7279	7.2710	21.3151	133.1557
Pavement Life Multiplier Factor (can leave as 1.0)	1.0000					
Length of road in this strength and life catergory	24	32	69	2,229	1,579	4,142
% of Network Length	0.3%	0.4%	0.9%	27.6%	19.6%	51.3%
Avg Pavement Mntce Cost (adjusted to match total spend) $/km	$ 211,864	$ 211,864	$ 211,864	$ 211,864	$ 211,864	$ 211,864
Cost $/km/ESA	$ 6.82	$ 0.80	$ 0.29	$ 0.03	$ 0.01	$ 0.00
Lives (MESA) before patching or pavement renewal	0.031	0.265	0.728	7.271	21.315	133.156

Figure 2-2 Network classification

The lives and the proportion of road network that relates to those lives can be given by Falling Weight Deflectometer or Traffic Speed Deflectometer Surveys. The amount of maintenance patches done per year could give an indication of the amount of weak road sections. It should be noted that any errors in over estimating or underestimating the lives and the various road lengths in each category are corrected for in the calculation sheet, automatically changing the average pavement maintenance costs so that the total maintenance cost calculated from the average heavy commercial vehicle combined with the total heavy vehicle kilometers travelled and the average heavy commercial vehicle cost per km is corrected. This ensures that the result of $ damage is always relative to the current maintenance spend along with total heavy vehicle kilometers travelled on the network regardless of the strength of the network.

2.3 Damage exponent values

Research at CAPTIF has shown that for weak pavements with short lives the damage exponent is higher than for strong pavements (background behind the values used are given in another paper). This result is not unexpected as weak pavements and/or pavement areas saturated with water can survive and not fail for light loads and cars but as soon as one heavy vehicle comes along the aggregates and subgrade can fail by shear. This sudden failure in shear results in high damage exponents (i.e. 1000s of loads for the lighter vehicle and say 1 load for the heavy vehicle).

Using higher damage exponents for the weak pavement classes will result in extra damage costs for the new heavy vehicle being analysed than using the 4th power value. Refer to Figure 2-3.

There is some debate what these damage exponent values should be and thus the user can change these values if they wish to test its effect. However, any changes made require the use of solver to adjust the costs from the existing traffic to match the current spend.

Exponent (axle loads > reference load)	9.05	5.65	3.49	1.90	1.10	1.05
Exponent (axle loads < reference load)	3.00	1.87	1.03	1.00	1.00	1.00

Figure 2-3 Damage exponent values

The user will notice that for loads less than the reference load the exponent values are less, this is because if both the new load and existing load are below the reference load then a higher damage exponent results in less difference in damage or less difference in damage cost.

More discussion on this issue of reference load is given below (*also note that there is another fix to this by reducing the reference loads and applying this to calculate ESA values by changing the factor from 1 to say 0.8 – refer to section 2.4*).

Basically the problem is to do with the new increased axle loads that are still less than the reference axle load and why it is important to add in the life of the pavement as demonstrated in the example below:

The formula to calculate ESA for one axle load is:

$$ESA = (\text{axle load}/\text{reference axle load})^n$$

If the reference twin axle load is 13,761 kg and we want to calculate the ESA loading for the actual axle load of 13,000 kg and an increase of the axle load to 13,500 kg, the solution is presented in Table 2-1:.

Table 2-1 Calculated ESA values example

Axle load	Weak road Exponent 9	Average road Exponent 4	Strong road Exponent 1.1
ESA for 13,000 kg	**0.6** = (13,000 / 13,761)^9	**0.75** = (13,000 / 13,761)^4	**0.85** = (13,000 / 13,761)^1.1
ESA for 13,500 kg	**0.84** = (13,500 / 13761)^9	**0.93** = (13,500 / 13,761)^4	**0.98** = (13,500 / 13,761)^1.1

Note how for the increase in load on the weak pavement with a damage exponent of 9, the result is a lower ESA value than for a stronger pavement.

The results in the above table look weird because it seems that there is less ESA loading on the weak road and thus maybe less RUCs. This is why it is important to add into the damage the life of the pavements and thus the damage cost per axle or vehicle pass.

The effect of a higher exponent value on loads less than the reference load is explained by the effect of the exponent. When the actual load is greater than the reference load (load ratio greater than unity), the higher exponent value will result in the damage value increasing at a larger rate than the standard exponent value of 4, however the same applies when the load ratio is less than unity, the damage factor will decrease faster than when the standard exponent is used. This effect is shown in Figure 2-4 below:

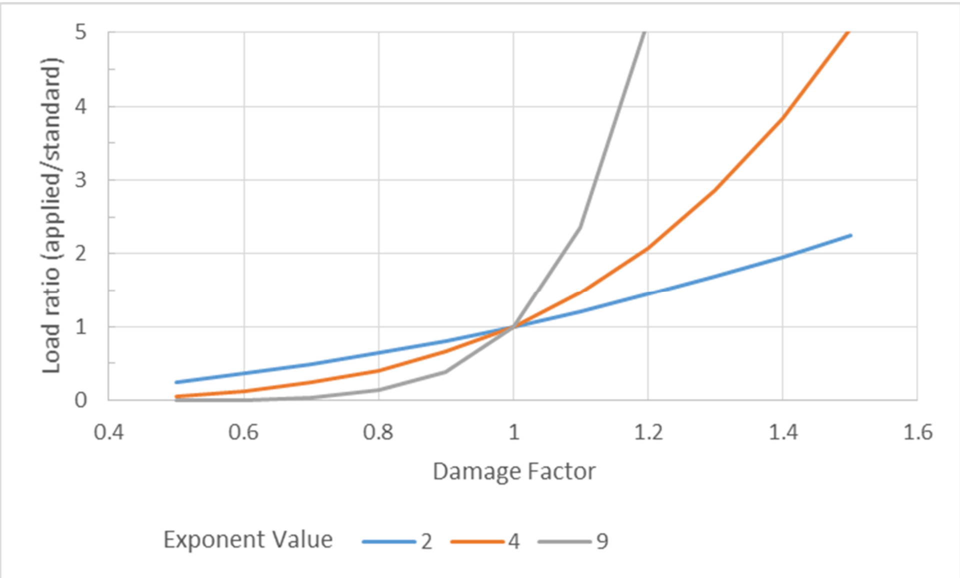

Figure 2-4 Damage exponent effect

This effect is negated by using an exponent value of 1.0 when the load ratio is less than unity.

The effect of adding pavement life is demonstrated below.

2.3.1 Weak road damage costs

Let us say the weak road (or weaker sections within a strong road) lasts 100,000 ESAs until it fails by rutting and require repair at a cost of $100,000 per lane km. For this weak road then very simply if you were to collect a toll for every lane kilometre travelled then you would need 1 dollar per ESA per km such that when 100,000 ESA passes are completed the road would have failed and you would have collected $100,000 to pay for the repair.

2.3.2 Average road damage costs

Let us say the average road (or average sections within a strong road) lasts 1,000,000 ESAs until it fails by rutting and require repair at a cost of $100,000 per lane km. For this average road then very simply if you were to collect a toll for every lane kilometre travelled then you would need 0.1 dollar per ESA per km such that when 1,000,000 ESA passes are completed the road would have failed and you would have collected $100,000 to pay for the repair.

2.3.3 Strong road damage costs

Let us say the strong road lasts 10,000,000 ESAs until it fails by rutting and require repair at a cost of $100,000 per lane km. For this strong road then very simply if you were to collect a toll for every lane kilometre travelled then you would need 0.01 dollar per ESA per km such that when 10,000,000 ESA passes are completed the road would have failed and you would have collected $100,000 to pay for the repair.

Using the ESA calculations above, the damage cost can be calculated using the lives for weak, average and strong roads as shown in the Table 2-2 below. The effect of adding in damage costs is 10 and 100 fold differences and it is the damage cost that was used and dominates the effect/damage of the different axle loads.

Table 2-2 Damage cost calculation example

Axle load	Weak road Exponent 9	Average road Exponent 4	Strong road Exponent 1.1
Damage cost per lane km for 13,000 kg	**0.6** $ per lane km = 0.6 x 1$ per ESA per km	**0.075** $ per lane km = 0.75 x 0.1 $ per ESA per km	**0.0085** $ per lane km = 0.85 x 0.01 $ per ESA per km
Damage cost per lane km for 13,500 kg	**0.84** $ per lane km = 0.84 x 1$ per ESA per km	**0.093** $ per lane km = 0.93 x 0.1 $ per ESA per km	**0.0098** $ per lane km = 0.98 x 0.01 $ per ESA per km

The above explains the issue and the reason why charges for vehicles need to consider the expected life of the road and not just the exponent value.

There is a second step after the cost calculations based on damage. This multiplies the average cost per vehicle by the number of vehicles over the year and adjust the cost per km to repair so that the total damage $ calculated matches the total $ spent for road damage from heavy vehicles.

Also, research at CAPTIF showed higher damage exponents for weak roads for axle loads that are higher than the reference load, in which case you do not get this problem.

2.4 AUSTROADS reference load adjustment factor

The AUSTROADS reference load adjustment factor in the calculation sheet is currently set at 1.0 which means that the AUSTROADS Reference Loads are not reduced – refer to Figure 2-5. This number can be changed to 0.8 if the vehicles being assessed have axle loads below the reference load. The reason is discussed in more detail above.

Figure 2-5 AUSTROADS reference load adjustment factor

2.5 HVKT per year and associated total maintenance spend per year

The HVKT (Heavy Vehicle Kilometres Travelled) per year is an important input – refer to Figure 2-6.

HVKT per year related to the $ spend on maintenance	1,515,298,390

Figure 2-6 HVKT per year

The HVKT is the total cumulative heavy vehicle kilometres travelled over the network in one year and is responsible for causing damage on the road network that results in the total maintenance cost per year.

The $ spent per year should only relate to pavement and surfacing damage caused by heavy vehicles. It should be noted that out of the total Road User Charges (RUC) income only 19.5% is allocated to structural and surfacing road maintenance (Ministry of Transport cost allocation model (CAM)). Thus, as a guide 19.5% of the total road budget can be used as the cost spent on structural repairs on the road network.

87,101,789	Input the $ spent per year related to pavement and surfacing damage by heavy vehicles

Figure 2-7 Maintenance cost

The total maintenance cost usually includes activities such as vegetation control, drainage maintenance, paint marking and sign maintenance etc, i.e. activities that are not related to pavement wear caused by heavy vehicles. If a roading authority has reliable cost data for the carriageway damage/maintenance component of their maintenance expenditure, then this figure can be used instead of 19.5% of their total maintenance expenditure.

2.6 Vehicle axle loads

Select the type of axle group as per the AUSTROADS referencing system along with their loads for both the current legal loads and the new proposed loads in the green cells indicated in Figure 2-8 below.

Also the tare weight of the vehicle is needed to allow the efficiency to be calculated that occurs by being able to carry more payload and thus less trips are required.

Axle group	Standard Axle Group Loads kN	Standard Axle Group Loads kg	GML Limits (kg)	HPMV Limits (kg)
SAST	53	5403	5400	6000
SADT	80	8155	8200	8800
TADT	135	13761	13500	15000
TRDT	181	18451	16000	18000
SAST(SS)	71	7238	10000	11000
QADT	221	22528	18000	22000
TAST	106	10805	10800	10800
NU	0	0	0	0

ANALYSIS VEHICLE									
	Axle groups ->	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	
	R12T22	SAST	TADT	TADT	TADT	NU	NU	Total (kg)
Current vehicle	Ref load (kg)	5,403	13,761	13,761	13,761	0	0	
	GVM (kg)	5,400	13,800	12,400	12,400	0	0	44,000
							Tare	15,763
							Payload	28,237
Case 1	Inc. load (kg)	5,400	14,200	12,700	12,700	0	0	45,000
							Load	*1,000*
							Increase	*2%*
							Payload	29,237
							Efficiency	97%

Figure 2-8 Vehicle axle loads

2.7 Loaded kilometers travelled per year for the vehicle being analysed and percentage uptake to the new load

Costs are calculated on a per vehicle bases per 1 km of road. To determine the total costs the total loaded kms (typically 60% of the total kms travelled) and the percentage of the vehicle type being analysed that will change to the new load, are needed. Refer to Figure 2-9.

Current loaded heavy veh km per year	87,541,213
% uptake	100

Figure 2-9 Loaded km travelled and estimated uptake

2.8 Spreadsheet calibration (important step that must be completed)

Spreadsheet Calibration is essential to ensure the calculated total maintenance cost equals the actual maintenance cost spend associated with damage caused by heavy vehicles.

Effectively the assumptions made on damage law exponents, pavement class lives and pavement class lengths, whether or not to reduce the AUSTROADS reference loads will in turn effect the ESA value of the average heavy commercial vehicle. The current budget spend per year on the network is fixed along with the heavy vehicle kilometres in the past year. If the calculated ESA increases for the average heavy vehicle due to assumptions made then the total ESA loading is higher for the network and thus for a fixed annual maintenance budget the maintenance cost per ESA or per average heavy vehicle pass is reduced. Likewise if assumptions made reduce the ESA for the average vehicle and thus reducing the total ESAs then maintenance cost per ESA increases.

Applying this calibration to total costs is important otherwise the calculated costs become grossly inaccurate.

Use solver which changes the rehabilitation cost multiplier from 1.0 (default) to something else to result in the total maintenance spend being the same as the total calculated maintenance spend. Instructions are in the spreadsheet as shown in Figure 2-10 below:

			The target cost is 19.5% of total cost (MoT CAM)		
	87,101,789	Input the $ spent per year related to pavement and surfacing damage by heavy vehicles			
Calc Total Spend	$ 87,101,789	2.119	Rehab cost Multiplier to match calculated cost with actual cost spent		
Difference	$ -		0	Use solver to make cell S22 minimum or zero by changing cell R21	

Figure 2-10 Calibration

The current version of the spreadsheet is set up as found typical for the whole of the State Highway where the average ESA per HCV is 1.67 and the average cost for the average HCV is $0.057 per km travelled. The values shown in Figure 2-11 should be reviewed with interest to see how the assumptions may affect these values and how they may differ from the typical State Highway values.

Avg ESA for all HCVs based on values given in this spreadsheet	1.67	
Cost per km per average HCV	**0.057**	$/km
Target cost per km per average HCV	0.057	$/km
Cost per km per avg HCV with ESA = 1.67 for the entire SH network	0.057	$/km

Figure 2-11 Average costs

2.9 Results

The total extra maintenance costs per year for a change in vehicle type per vehicle is shown at the bottom of the screen in red bold text. It is important for this calculation that the loaded vehicle kilometres travelled over the network are accurate. If looking at the impact of many different vehicles a good idea is to add up all their loaded kilometres and make sure they are a fraction (i.e. cannot exceed 100% and more likely should only be around 20% of the fleet or the total heavy vehicle kilometres travelled) of the total heavy vehicle kilometres on the network. One way of estimating the total loaded vehicle kilometres is to estimate a % of the total fleet.

Other values in red text show the maintenance cost per kilometre per pass which could be used to populate a different spreadsheet with a range of different heavy vehicles.

An example of the final output is presented in Figure 2-12

ESA		3.44		3.66		3.81		3.81		3.80		3.80
$/km/1 veh pass	$	23.45	$	2.92	$	1.11	$	0.11	$	0.04	$	0.01
Total $ / 1 veh pass	$	555.87	$	92.61	$	76.57	$	247.28	$	59.71	$	25.07
Average $/km/1 veh pass						0.13						
ESA		3.86		3.91		3.96		3.91		3.88		3.88
$/km/1 veh pass	$	26.31	$	3.12	$	1.15	$	0.11	$	0.04	$	0.01
Total $ / 1 veh pass	$	623.81	$	99.01	$	79.61	$	253.75	$	60.90	$	25.56
Average $/km/1 veh pass						0.14						
Extra $/km/1 veh pass						0.01						
Current loaded heavy veh km per year		87,541,213										
% uptake		100										
Current loaded veh km per year that will change		87,541,213										
New veh km per year incl efficiency		84,547,020										
Extra $ pavement wear	$	503,454										

Figure 2-12 Outputs

3. References

IDS (2016). *Pavement Cost Impact Assessment from Increased Axle Loads on 2 and 3-Axle Buses and Trucks.* Wellington, New Zealand (https://www.nzta.govt.nz/about-us/consultations/land-transport-rule-vehicle-dimensions-and-mass-2016).

IDS (2016). *Pavement Cost Impact Assessment from Increased Gross Vehicle Mass on 7 & 8-axle Combination Vehicles.* Wellington, New Zealand (https://www.nzta.govt.nz/about-us/consultations/land-transport-rule-vehicle-dimensions-and-mass-2016).