Absolutely Positively
Wellington City Council
Me Heke Ki Pōneke

9 August 2022

File ref: IRC-3608

[redacted]

Kia Ora [redacted]

Thank you for your request transferred from Greater Wellington Regional Council to Wellington City Council, made under the Local Government Official Information and Meetings Act 1987 (the Act), received on 12 July 2022. You requested the following information:

- Any studies or reports produced between 2018 until now, and held by Greater Wellington Regional Council, which model or analyse the road wear impact of battery-electric buses on streets and roads.

Wellington City Council has **granted** your request for information.

Below are the documents that fall in scope of your request and my decision to release the document.

Item	Document name/description	Decision
1.	2019 Pavement impact assessment from increased axle loads Year 1	Release with redactions
2.	2019 dTIMS Report Summary Pavement Model Outcome	Release with redactions
3.	2020 Update Pavement impact dTIMS assessment from increased axle loads	Release with redactions

Please note:

- Some information has been withheld under section 7(2)(a) of the Act to protect the privacy of individuals.
- Costs provided in the report are only estimations and not actual charges.

There is also some information on the NZTA website regarding vehicle dimensions and mass permitting manuals, which might also help with your research.

Right of review

If you are not satisfied with the Council's response, you may request the Office of the Ombudsman to investigate the Council's decision. Further information is available on the Ombudsman website, www.ombudsman.parliament.nz.

Please note, we may proactively release our response to your request with your personal information removed.

Thank you again for your request, if you have any questions, please feel free to contact me.

Kind regards
Asha Harry
Official Information

Wellington City Council

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IDS

Assessment of pavement impacts associated with increased bus axle loads on the Wellington City road network

Year 1 update

October 2019

IDS - Infrastructure Decision Support

A non-profit, industry driven organisation owned by IPWEA New Zealand
http://www.ids.org.nz/

Quality Assurance Statement		
Infrastructure Decision Support PO Box 25415, Featherstone Street Wellington 6146 New Zealand	Project team:	Bruce Steven, Greg Arnold, Riaan Theron
	Reviewed by:	David Alabaster, John Hallett …………………………………………………
	Approved for issue by:	Theuns Henning …………………………………………………
	Update Year 1 Reviewed by:	Bruce Steven
	Update year 1 Approved for issue by:	Theuns Henning …………………………………………………

Revision Schedule			
Rev No.	Prepared by	Description	Date
A	Riaan Theron	Draft for review	23/12/2018
B	Riaan Theron	Final	07/03/2019
C	Shania Bibby	Draft update with Year 1 passenger data for review	13/09/2019

Executive Summary

Greater Wellington Regional Council (GWRC) has embarked on a programme to improve public transport in the region which includes the replacement of trolley buses in their bus fleet with a number of high capacity urban buses (Electric and Diesel Double Decker buses). These new buses will be operating at axle masses that are greater than the allowable axle masses for general access as defined in the Vehicle Dimensions and Mass Rule (VDAM) when a certain passenger number is exceed.

The introduction of these buses is likely to cause increased pavement wear on the Wellington City Council (WCC) road network depending on the type of bus and the routes followed. This potential increase in road maintenance costs is of concern to the Council.

The primary objective of this study is to assess the additional pavement wear-related costs that could be attributed to an increase in the axle mass for the high capacity urban buses on the WCC road network. This report summarises the results from the analysis based on historic pavement and surfacing maintenance cost on the network, and selected bus axle and load configurations.

For the purposes of this study, the cost of additional pavement wear due to the new electric and diesel double decker buses is defined as the cost of pavement wear that occurs when a vehicle is estimated to be operating with axle masses that are greater than the allowable axle masses for General Access (GA) as defined in the VDAM Rule.

It is expected that more of these high capacity urban buses will be introduced to the bus fleet over a period of time. This report focusses on the additional cost in year 1 of the bus fleet operating under the current numbers as agreed with GWRC and WCC. This provides the opportunity to update the report in following years with actual passenger numbers and updated maintenance costs.

The estimated additional pavement maintenance costs occurred when DDD and EVDD buses are operating above the GA mass limits for the first year of operation is:

DDD	$70,850
EVDD	$95,900
Total Additional Cost	$166,750

Year 1 Update

Following the implementation of the double decker buses on the Wellington City network, GWRC provided actual bus user data for the period between March 2019 and July 2019. This user data was used to update the occupancy/actual bus loading and the total vehicle kilometres travelled on the WCC network. The data was pro-rated up to 12 months to calculate the total additional maintenance costs, which is summarised below:

DDD	$18,714
EVDD	$39,931
Total Additional Cost	$58,645

The significant reduction in the estimated costs is due to a slower than expected rollout of the EVDD and DDD buses on the network and the difference between the estimated and actual loading distributions. The updated model outcomes are discussed in section 6 of the report.

Contents

Definitions and 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 used as a means of normalising different axle weights and configurations loads to allow an estimate of the relative damage caused
GA	General Access. A vehicle that can operate without a permit, subject to any specific route or bridge restrictions
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 mass
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
HCUB	High Capacity Urban Bus. A heavy passenger service vehicle fitted with seating positions for 60 or more passengers that is operating in a public transport service that is identified in or under a regional public transport plan as defined in the Land Transport Management Act 2003
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 mass at normal highway speeds, count and classify vehicles numbers

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

1. Introduction

1.1 Background

The Greater Wellington Regional Council (GWRC) has embarked on a programme to improve public transport in the region which includes the replacement of trolley buses in their bus fleet with a number of high capacity urban buses (HCUB). One of the reasons why the GWRC wanted to introduce HCUBs to the network was to reduce the bus congestion in the CBD area. This process commenced in late 2017 following submissions from various transport operators for an improved bus service.

In 2010 NZTA introduced a new class of heavy vehicle called a High Productivity Motor Vehicle (HPMV). These vehicles can operate with masses or dimensions greater than that permitted for an ordinary (General Access (GA)) heavy vehicle. A HPMV can be granted a permit to operate with higher axle masses (up to a specified maximum) either over a specified route or a general area as determined by the Road Controlling Authority (RCA), WCC in the case. In 2016 the VDAM Rule was amended to create a Specialist Vehicle category that includes passenger service vehicles. This amendment allowed specialist vehicles to operate under a permit with axle masses that are greater than those allowed for GA and HPMV vehicles.

The new GWRC fleet comprises of a combination of Electric (EVDD) and Diesel Double Decker buses (DDD) and vehicles from the current fleet (excluding trolley buses). These new buses will be operating at axle masses that are greater than the allowable axle masses for General Access (GA) as defined in the Vehicle Dimensions and Mass Rule (VDAM) and therefore will require a specialist vehicle permit to enable the buses to be able to carry the maximum number of passengers that they have been designed to carry.

It is expected that more of these HCUBs will be introduced to the bus fleet over a period of time as the expected demand for public transport increases. This fleet will continue to use the current bus routes on the WCC road network.

1.2 Problem statement

The planned replacement of the trolley buses with a newly configured bus fleet, which will include high capacity urban buses, is likely to cause increased pavement wear on the WCC road network depending on the type of bus and the routes followed. Although these vehicles will operate under permit, the magnitude of the pavement damage caused is yet to be determined. This potential increase in road maintenance costs is of concern to WCC.

1.3 Study 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 axle masses for urban buses on the WCC road network.

For the purposes of this study, the cost of additional pavement wear due to the new Electric (EVDD) and Diesel Double Decker buses (DDD is defined as the cost of pavement wear that occurs when a vehicle is estimated to be operating with axle masses that are greater than the allowable axle masses for General Access (GA) as defined in the VDAM Rule. The cost of the pavement wear caused by any heavy vehicle that is operating under the GA limits is assumed to be included in the existing road maintenance budget.

1.4 Scope

The pavement impacts from buses with a range of axle combinations and masses that covers the re-configured bus fleet on the GWRC-defined bus routes, were assessed using the IDS pavement wear cost estimation model.

This report summarises the results from the analysis based on pavement and surfacing maintenance cost on the network, and selected bus axle and load configurations.

It is expected that more of these high capacity urban buses will be introduced to the bus fleet over a period of time. This report focusses on the additional cost in year 1 of the bus fleet operating under the current numbers as agreed with GWRC and WCC. This provides the opportunity to update the report in following years with actual passenger numbers and updated maintenance costs.

No physical pavement testing was undertaken on the proposed bus routes. The cost impact on bridge structures and current State Highway sections within the WCC network are excluded from this study.

Representatives from the key interested parties (WCC, GWRC and the NZ Transport Agency) worked collaboratively on this study to define the potential cost impact associated with the increase in bus axle masses towards an agreed funding model between them.

GWRC has reviewed the IDS draft report of January 2018 and provided their comments in a memorandum which is included in Appendix A of this report. A record of the written communication between IDS and GWRC is included in Appendix B.

2. Vehicle loading and movements

2.1 Vehicle Dimension and Mass Rule (VDAM)

The legislated vehicle and mass limits in New Zealand are outlined in *The Land Transport Rule: Vehicle Dimensions and Mass 2016 Rule* 41001/2016 (VDAM), which came into force on 1 February 2017. This rule outlines the vehicle mass limits for *Public Service Vehicles* applicable to this study and can be summarised as follows:

Table 2.1 General Access Mass Limits for Public Service Vehicles (Buses)

Maximum mass on individual axles		
Single standard tyres	In a tandem axle set with twin-tyred axle	5,800kg
	In any other axle set	6,000kg
Twin tyred	In a tandem axle set with single standard-tyred axle	8,700kg
	In any other axle set	8,200kg* (9,000kg from 1/12/2018)
Maximum total mass on two axles in a tandem set		
Twin tyred axle	With a single standard-tyred axle and load share of 60/40	14,500kg
	With a single standard-tyred axle or single mega-tyred axle and load share between 60/40 and 55/45	14,500kg
Maximum total mass	Length between 8m and 14m	Between 30,000kg and 40,000kg

Table 2.2 Specialist Vehicle Mass Limits for Public Service Vehicles (Buses)

Maximum mass on individual axles		
Single large tyre	In a tandem axle set with twin-tyred axle and a 55/45 load share	8,100kg
Twin tyred	In any axle set	12,000kg
Maximum total mass on two axles in a tandem set		
Twin tyred axle	With a single large-tyred axle and load share of 60/40	16,000kg
	With a single large-tyred axle and load share of 55/45	18,000kg
Maximum total mass	Length between 8m and 14m	Between 30,000kg and 40,000kg

This rule allows for heavy vehicles to operate under permit at sizes and weights above the standard legal maxima on approved roads within New Zealand.

2.2 GWRC bus details

The bus fleet used on the WCC network comprises a range of makes and models. Data on the buses of interest (EVDD and DDD) was supplied by GWRC and summarised in Table 2.3.

Table 2.3 HCUB details

Bus	Axle Design Mass			Number of passengers at 100% loading	Number of passengers when rear axle exceeds GA limits
	Front	Rear	Total		
EVDD 2-axles	6,760kg	11,950kg	18,710kg	80	36 @ 8,200kg (42 @ 9,000kg from1/12/2018)
DDD 3-axles	7,120kg	15,888kg	23,008kg	101	82 @ 14,500kg

2.3 Definition of this study

For the purposes of this study, the cost of additional pavement wear due to the new electric and diesel double decker buses is defined as the cost of pavement wear that occurs when a vehicle is estimated to be operating with axle masses that are greater than the allowable axle masses for General Access (GA) as defined in the VDAM Rule.

3. Model development

Previously IDS has developed a model that allows the cost, in terms of pavement wear, to be calculated for a specific vehicle travelling over a specified route. The cost is calculated by considering the historical maintenance costs, historical heavy vehicle volumes, current pavement strength and proposed vehicle configurations and usage. The model is scalable from a single vehicle on a specific route to a fleet operating over a network.

For this study, the cost of a specific vehicle travelling on a specific route was calculated for a number of different HCUB operating on various routes. The IDS pavement wear cost estimation model requires five inputs:

1. A defined network (the *network*)
2. Annual Maintenance cost for the network
3. Distribution of the pavement strength or remaining life of the network
4. Annual HVKT for the network
5. Details of the proposed HCV that will be used on the network including axle/load configurations and proposed HVKT

3.1 A defined network (the *network*)

The datasets available to this study had sufficient detail to allow each route of the proposed bus network to be modelled as a separate network.

The RAMM carriageway sections on the proposed bus routes were grouped into CBD, north and south segments for each proposed route. This enabled a hub (CBD) and spoke (north or south segment) network model to be created. Only roads that are owned by the WCC are included in the model, i.e. State Highways are excluded from the analysis.

3.2 Annual maintenance cost for the network

The WCC provided all of the individual maintenance activities and claimed costs for the bus routes for the previous 5 years i.e. 2012 - 2016. This information was obtained from the RAMM Contractor platform where each contractor claim resulting from a maintenance activity is allocated to the relevant RAMM carriageway section. Altogether 8772 line items and 1900 separate RAMM carriageway sections were reviewed and a total spend of $54m was reported for the above period, or $10.8m per annum. Roads that are part of the proposed DD bus routes have an historical maintenance expenditure of $3.38M per annum.

This information is considered to be comprehensive as the maintenance contractor is required to track and claim their maintenance activities in the RAMM Contractor environment. The actual claim costs were increased by 25% to cover the fixed contract and WCC administration costs.

The annual maintenance cost for each spoke was calculated using the network and cost datasets associated with each spoke as described above. This customised annual cost was used as the annual maintenance cost input for the cost calculator spreadsheet.

3.3 Distribution of the pavement strength or remaining life of the network

The cost calculator spreadsheet requires the distribution of the remaining life of the pavement for the network under consideration to be allocated into six categories. For this project the allocation was based on recent work completed by Geosolve where each RAMM treatment length section was allocated a remaining life. There were a number of sections that did not have a Geosolve rating, these sections were allocated a remaining life value based on the spread of the remaining life values of sections in that network/route under consideration.

3.4 Annual HVKT for the network

The total HVKT for each spoke was calculated by using the HVKT data contained in the RAMM dataset. Each carriageway section in the RAMM dataset has a HVKT value assigned to it, this value is the product of the AADT, carriageway length and percentage of HCV. For each spoke, the HVKT values for each carriageway section were summed to give the HVKT total for the spoke.

Bus volumes as a percentage of total HCV range from 9 to 44%.

3.5 Details of the proposed buses that will be used on the network

The buses of interest to this study are the three axle Diesel Double Decker Buses (DDD) and two axle Electric Vehicle Double Decker Buses (EVDD).

3.5.1 Axle/load configurations and proposed HVKT

The total bus HVKT and axle loading for each network was determined by breaking down the proposed timetables into northern, southern and CBD trips and then allocating each trip to either peak or off-peak. Peak trips were trips that either:

a) Arrived at the edge of the CBD between 6am and 9am on a weekday, or

b) Departed the CBD between 4pm and 6pm on a weekday.

All other trips were classified as off-peak trips. Peak trips were assumed to have a 100% loading and off-peak trips were assumed to have a 35% loading. The proposed timetables indicated the type of vehicle to be used, large vehicle (LV) or double decker (DD), LVs were assumed to be a 3 axle vehicle with a capacity of 83 passengers and DDs were assumed be a 3 axle vehicle with a capacity of 101 passengers.

It has been assumed that the LV buses are already operating on the routes with axle masses under the GA limits and that the pavement wear caused by these LV buses is already covered by the current pavement maintenance costs.

The pavement wear caused by the buses operating at 35% capacity during the off-peak period is approximately a third of the damage caused by the buses loaded to 100% and is not included in the results presented in this memorandum.

An assessment of the tare weights and front/rear load distributions were made to enable the relative pavement wear calculations to be performed. The assumed load distributions are based on information received from GWRC and are shown in Table 3.1. Due to the way the pavement wear model is configured, the design vehicles are assumed to operate at their maximum masses over the entire network, this approach produces an upper bound cost which provides some allowance for unquantified events/costs.

The bus HVKT values for each network were calculated by multiplying the number of trips per week by 52 weeks per year by the length of the network. These values were checked against the total HVKT for each network and it was observed that the bus HVKT value was less than the total HVKT for the network. This gave confidence that the traffic data in the RAMM database was realistic.

The vehicle efficiency gained from using the higher capacity DD buses was calculated on the basis that additional LV trips would be required to transport the number of passengers that would be carried on the network by DD buses at the proposed frequencies.

GWRC has provided a report that gives the passenger loading when the axle masses are equal to the GA limits and an estimate of the passenger loading density for the CBD and urban zones.

This information was used to calculate a weighted cost based on the percentage of time in different loading ranges (10% bands) for when the bus was operating with axle masses above the GA limits. To do this, the calculated cost for a bus operating at a specified passenger loading was multiplied by the percentage of time at that level of passenger loading to arrive at the weighted cost for that passenger loading. The individual weighted costs were then added together to give a total weighted cost for the route.

GWRC have indicated that after the first year of operation, they will have sufficient passenger trip data to provide to be able to generate an accurate spectrum of passenger loading data.

Table 3.1 Bus Loading Summary

		Front (Single Axle/Single Tyre)	Rear (Double Axle/Dual + Single Tyre)	Rear (Single Axle/Dual Tyre)	Total
DDD	Tare (t)	4.24	10.69	-	14.93
	Passenger No			-	101
	Passenger Mass (t)	2.88	5.20	-	8.08
	Total Mass (t)	7.12	15.89	-	23.01
	ESA (4th Power)	2.80	3.37	-	6.17
	Reference Load (t)	5.5	11.7	-	
EVDD	Tare (t)	4.20	-	8.03	12.23
	Passenger No		-		81
	Passenger Mass (t)	2.56	-	3.92	6.48
	Total Mass (t)	6.76	-	11.95	18.71
	ESA (4th Power)	2.27	-	4.51	6.78
	Reference Load (t)	5.5	-	8.2	

3.5.2 Number of buses

GWRC has also provided the anticipated EVDD and DDD bus numbers for each bus operator and routes in year 1. This included the percentage of the year that the buses were in service as some DDDs are not programmed to enter service until either October 2018 or January 2019.

The costs are based on 10 EVDD and 51 DDD buses in year 1. The DDD breakdown is 28 for 12 months, 6 for 9 months and 17 for 6 months.

The output of the cost model was altered to provide a cost per route assuming 1 bus trip per route per weekday (250 trips per year). This change allowed us to calculate the cost for a specified number of buses rather than assuming that all peak period buses were operating in the HPMV range.

3.5.3 Bus Stops

The annual cost of reconstructing bus stops has been estimated at $750,000 per year. An amount has been allocated to the EVDD/DDD costs by the following methodology:

a) The pavement wear cost is calculated where the EVDD/DDDs are replaced by LVs ($10,970);

b) This cost is converted into a percentage of the annual maintenance cost on the bus routes ($2,609,592). This calculated percentage is then multiplied by the estimated bus stop costs (0.42% x $750,000 = $3,153);

c) The EVDD/DDD have, on average, an ESA multiplier of 12 compared to an LV. The bus stop cost calculated above is factored by the multiplier to give an additional annual cost of ($3,153 x 12 = $37,836).

4. Route costs

The results from the analysis are summarised in Table 4.1 and in full at the rear of this document. The total expected additional cost per annum from an increase in bus axle weights for all routes is $946k on a bus route spend of $3.3M.

The annual additional spend on bus stop maintenance was calculated at $750k, assuming a high volume route would last five years and the lower volumes were prorated up. It is expected that the 12t single-axle dual-tyre rear axle of the EVDD will cause significant damage to the stops for both surfacing and structural. This additional cost is not included in the results.

Table 4.1 Summary of costs per route per year

Diesel Double Decker Buses (DDD)			Electric Vehicle Double Decker Buses (EVDD		
Route	No. Trips/day	Cost	Route	No. Trips/day	Cost
1	12	$ 11,430	1	24	$ 44,329
7	11	$ 4,027	7	16	$ 11,053
23e	9	$ 7,316	23e	6	$ 9,434
32x	13	$ 12,105	32x	6	$ 16,895
3	17	$ 4,210	-	-	-
31x	6	$ 2,268	-	-	-
36	6	$ 1,988	-	-	-
56	2	$ 1,070	-	-	-
57	4	$ 2,236	-	-	-
58	1	$ 528	-	-	-
Annual Pavement Cost		$ 47,178			$ 81,711
Bus stop cost		$ 23,656			$ 14,179
Total		$ 70,850			$ 95,900
Total Cost		$ 166,750			

In addition to the calculation of the additional wear cost as detailed above, the pavement wear cost that would be attributed to the bus traffic on a route if the bus was operating under GA limits was calculated. This was done to provide a relativity check on the additional estimated costs for the HCUBs. These base costs for the nominated routes are given in Table 4.2 and show that the estimated pavement wear costs that would be incurred if the routes were serviced by regular single deck buses (LVs) is $379k per year for all the trips on the routes and that the addition of a limited number of HCUBs results in additional $167k per year, an additional 44% on the nominated routes.

Table 4.2 Summary of costs per route per year for GA buses

Route	Cost
1	$ 221,096
7	$ 69,310
23e	$ 39,816
32x	$ 4,239
3	$ 6,142
31x	$ 6,245
36	$ 6,416
56	$ 9,635
57	$ 13,616
58	$ 2,165
Annual Pavement Cost for GA buses	$ 378,680

5. Conclusion

The additional pavement wear-related costs that could be attributed to an increase in the axle mass for the high capacity urban buses (EVDD and DDD) on the WCC road network was determined using historic pavement and surfacing maintenance cost on the network, and selected bus axle and load configurations.

The cost of additional pavement wear due to the new EVDD and DDD buses is defined as the cost of pavement wear that occurs when a vehicle is estimated to be operating with axle masses that are greater than the allowable axle masses for General Access (GA) as defined in the VDAM Rule.

It is expected that more of these high capacity urban buses will be introduced to the bus fleet over a period of time. This report focusses on the additional cost in year 1 of the bus fleet operating under the current numbers as agreed with GWRC and WCC. This provides the opportunity to update the report in following years with actual passenger numbers and updated maintenance costs.

The estimated additional pavement maintenance costs occurred when DDD and EVDD buses are operating above the GA mass limits for the first year of operation is:

DDD	$70,850
EVDD	$95,900
Total Additional Cost	$166,750

6. Updated Model with Actual Passenger Numbers

GWRC provided passenger data for the bus operations between 01 March 2019 and 31 July 2019. This passenger data was used to update the estimated loading in the previous model. The total BVKT over this period was used and was prorated up to 12 months based on the information provided i.e. all bus trips were considered in the analysis and not just peak hour trips per phase one study. The total BVKT used in the analysis is summarised below.

Table 6.1 Total BVKT

Vehicle	Route	Zone	BVKT (Mar to July)	BVKT per year
DDD	1	CBD	76,074	182,577
		NORTHERN	108,964	261,513
		SOUTHERN	56,767	136,241
	3	CBD	26,183	62,839
		SOUTHERN	52,817	126,761
	7	CBD	13,598	32,635
		SOUTHERN	20,183	48,440
	36	CBD	1,701	4,082
		SOUTHERN	3,906	9,375
	56	CBD	2,554	6,129
		NORTHERN	3,690	8,855
	57	CBD	4,311	10,347
		NORTHERN	5,640	13,536
	58	CBD	3,056	7,334
		NORTHERN	4,344	10,426
	23e	CBD	4,410	10,584
		SOUTHERN	6,137	14,729
	31x	CBD	3,791	9,099
		SOUTHERN	5,024	12,058
	32x	CBD	7,961	19,107
		SOUTHERN	9,497	22,794
EVDD	1	CBD	23,285	55,883
		NORTHERN	33,538	80,492
		SOUTHERN	16,400	39,361
	7	CBD	6,025	14,461
		SOUTHERN	9,030	21,671
	23e	CBD	836	2,006
		SOUTHERN	1,025	2,460
	32x	CBD	760	1,823
		SOUTHERN	1,045	2,507
Total BVKT			512,551	1,230,124

Maintenance costs and pavement condition was assumed to be the same as phase one of the analysis. The timetabled annual BKVT for all services on the listed routes is 4,417,178 km. This means that the DDD and EVDD vehicles currently make up 28% of the BKVT on the listed routes.

6.1 Passenger Occupancy Distribution

Analysis of the passenger data showed that the passenger occupancy distribution was significantly different to that assumed during phase 1 of the study. This was updated in the model for each route per the actual occupancy distribution.

The data provided only showed the occupancy per each “tag on/off” of the bus-card user and do not include the cash passengers. Therefore, there are trips where the occupancy of the vehicle is <0. It was assumed that the proportion of cash passengers were low and do not place a significant impact on the overall loading distribution of the buses.

It was also noted that the maximum occupancy of both the DDD (101 passengers) and EVDD (83 passengers) vehicles were exceeded on all routes – majority of which occurred in the CBD zone. Refer to Table 6.2.

Table 6.2 BVKT Operated Over Capacity

Route	BVKT DDD occupancy ≥110 (km)	BVKT EVDD occupancy ≥90 (km)
1	163	163
7	25	22
23e	1	2
32x	63	11
3	45	
36	15	
56	15	
57	50	
58	16	
31x	7	

The recorded passenger occupancy is significantly different to that assumed in the original analysis. The recorded passenger information shows that the DDD and EVDD were loaded greater than 80% occupancy for less than 2% of the total distance travelled across both the CBD and Northern and Southern zone. Compared to the original assumption that 45% of all peak services in the CBD and 11% in the Northern and Southern areas would be loaded to 80% capacity or above.

It should also be noted that the introduction of the HCUBs has been slower that assumed over the first 12 months of the new contracts.

The recorded passenger occupancy distribution as a percentage of total bus kilometres travelled is summarised in Figure 6-2 below and the original distribution of bus loadings is presented in Figure 6-1 for reference.

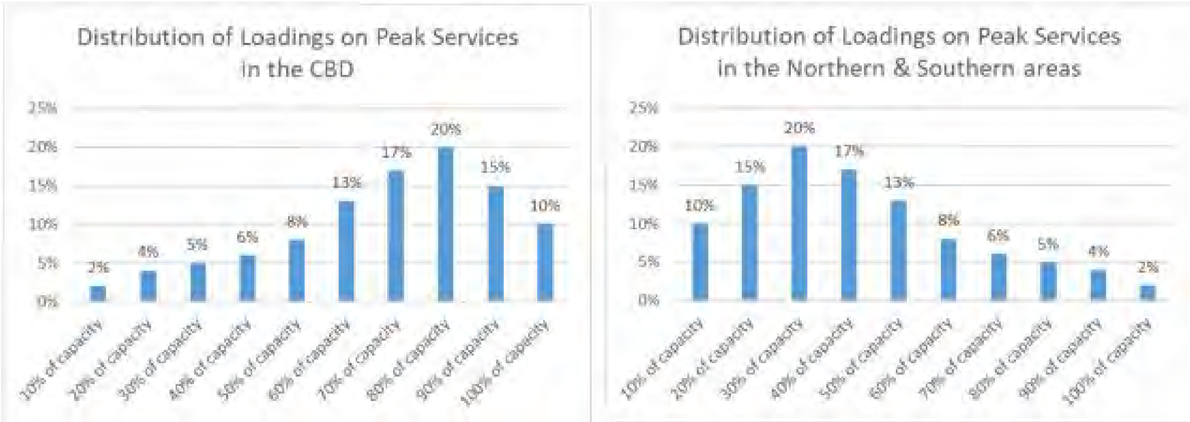

Figure 6-1 Estimate of Distribution for Peak Loadings

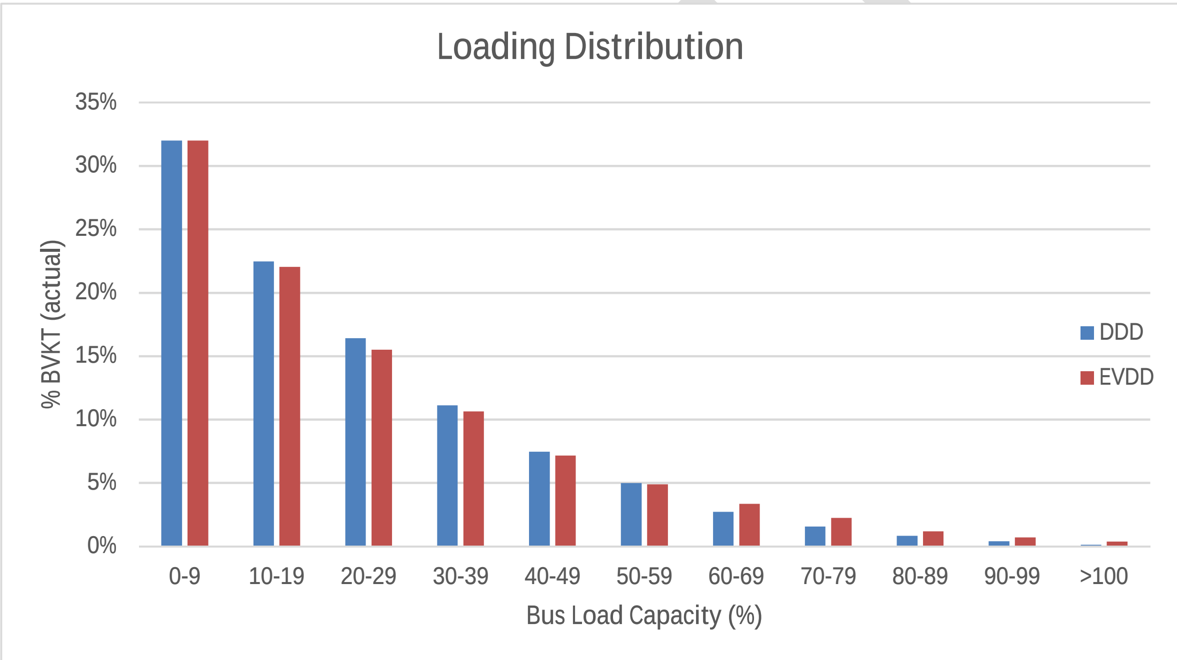

Figure 6-2 Actual Distribution for all Bus Trips

6.2 Updated Route Costs

Based on the actual loading distribution above, the calculated total additional annual cost is $58,645 p.a. This is summarized in Table 6.3 below.

Table 6.3 Summary of costs per route per year (actual BVKT)

Diesel Double Decker (DDD)		Electric Vehicle Double Decker Buses (EVDD)	
Route	Cost	Route	Cost
1	$ 5,974	1	$ 21,063
7	$ 423	7	$ 834
23e	$ 86	23e	$ 301
32x	$ 2,962	32x	$ 8,901
3	$ 736		
31x	$ 630		
36	$ 435		
56	$ 177		
57	$ 955		
58	$ 241		
Annual Pavement Cost	$ 12,618		$ 31,099
Bus stop cost	$ 6,096		$ 8,833
Sub-Total	$ 18,714		$ 39,931
Total			$ 58,645

Appendix A

GWRC feedback memo on IDS summary Report of 27/06/2018

Appendix B

GWRC Correspondence

Paul Blane (28/06/2018)

From: Paul Blane [redacted]
Sent: Thursday, 28 June 2018 7:04 p.m.
To: Bruce Steven [redacted]
Cc: Arne Brandt [redacted]
Subject: WCC Pavement Wear Modelling

Bruce

Attached is the work that Arnie has done post our meeting. I think I had provided some loading data in the past, but to make sure the data is up to date and given that two of the three DD buses have now been built, I have attached weight distribution data for both brands of the diesel DD buses that will be in operation. Unfortunately I can't provide a drawing with load data for the EVDD as the manufacturer is super sensitive about it due to the fact it is a new design. However the basic data is in the table below.

EVDD

Front axle load 7200kg

Rear axle load 12,000kg

Passenger loading max 80 (from loading cert)

Wheelbase 5350mm

Front overhang 2355mm

Rear overhang 2693mm

Paul Blane (02/07/2018)

I have been back over the axle loading data at which the rear axles exceed the general access limits and find the estimates I provided previously are still a good number to use. It is little unpredictable as to where passengers may not be as the numbers reduce. I removed most of the passengers from the rear row forward of the upper deck as they are the furthest from the stairs and I feel the least likely to be used plus the last couple of rows on the lower deck in determining the effect of the mass reduction. I have used 80kg per passenger and ignored the fact that the passengers in the rows behind the rear axle will apply slightly more than 80kg on the rear axle/s. While it is typical for passengers to spread out initially, but as the passenger load increases passengers tend to gravitate around the doors to make the exit easier. I have also found that passengers will still stand as a preference to sitting next to someone. This will have the effect of increasing the load towards the front of the bus.

	Passenger # at 100% loading	Passenger # when rear axle exceeds general access limits
EVDD	80	36 @8700kg to 30/11/18
EVDD	80	42 @ 9000kg from 1/12/18
Diesel DD	101 & 102	82 @ 14500kg

Regards.

Paul

Communication with Paul Blane (02/05/2018)

Hi Paul/Arne

Following the conversation this morning between Paul and myself, the current situation is that IDS completed their initial modelling based on the timetable data for 13 routes that was provided to IDS in 2017. For each of the supplied routes, the timetables showed the required bus capacity (SV, LV, DD) for peak and off-peak periods. The modelling was based on these expected vehicle repetitions/trips. Earlier this year IDS received specific bus information and DD trip numbers for 3 of those routes. Paul confirmed that on July 1 this year, those three routes are the only routes that will have DD buses operating on them. All other routes will be serviced by LV (3 axle single deck) buses that operate under VDAM General Access rules – i.e. do not require a HPMV permit.

The model is constructed in a way that as specific DD vehicle/route information is received, the additional damage estimate for that route can be easily calculated.

My understanding of the outstanding issues are:

1. GWRC understanding of the model mechanics – IDS to supply a model schematic and talk it through with Arne.
2. Discrepancy between bus HVKT figures calculated by IDS and GWRC – to be resolved.

The following issues have general agreement between the parties:

1. Bus loading rates are estimates and there is a need to trade-off loading based on expected numbers and spatial (route) distributions and loading levels that HPMV permits are issued for, i.e. max permitted load vs actual load – similar to RUC rules.
2. The model inputs (and outputs) can be reassessed after 12 months operation when actual maintenance and loading data is available as this data will/is be collected electronically and is owned by either WCC (maintenance) or GWRC (loading).

I will supply the model schematic to Arne this week and are available to talk it through.

Bruce

Paul Blane (24/03/2018)

Hi Paul, (From Bruce 16/02/2018)

We understand that via WCC the bus companies intended to use 47 diesel DD and 10 EVDD buses on the new bus routes. Based on the supplied timetables we have assumed that the routes/peak/interpeak required bus capacities (SV/LV/DD) are as stated in the timetables.

In order to refine the costing model are you able to tell us:

1. The routes that the diesel DDs will be used on. 1, 7, 23e, 32x, 56, 57, 58, 3, 31x, 36, 81, 85x
2. The routes that the EVDDs will be used on. 1, 7, 23e, 32x
3. For the EVDD routes, what percentage or number of the peak trips will be EVDD, assuming that the balance, if any, would be DD. See above.
4. That there will be sufficient DD to satisfy your timetable requirements. Yes

Thanks,

Bruce

Please see below responses to your questions.

- Route 1 will have 102 return trips per 18 hour period with up to 30 of these being done by the EVDD. up to 60 of these being operated by diesel double decker
- Route 7 will have 64 return trips per 16 hour period with up to 20 of these being done by the EVDD. up to 30 of these being operated by diesel double decker.
- Route 23 will have 9 inward trips over morning peak only with 3 of these being done by the EVDD and 3 by a diesel DD and 10 outward trips in the PM peak with again 3 being operated by EV DD and 3 by a diesel DD.
- Route 32 will have 8 inward trips over morning and a similar number of outward trips in the afternoon peak only with 3 of these being done by the EVDD and 5 by a diesel DD.

The balance of the above trips will be by LV. I am waiting for information on the number of DD trips for the other routes. I will provide this ASAP.

I also now have the axle loading distribution for the diesel DD buses from the manufacturers as follows:

BCI DD Front 7161kg rear 15959kg

ADL DD front 6992kg rear 15948kg

Note that none of the LV buses require a permit and in the case of the EVDD the general access rear axle mass limit from 1/12/18 will go up from 8700kg to 9000kg.

Paul Blane (17/11/2017)

Bruce

Received more data.

DD

Axle 1 tyre size 355/50R 22.5

Axle 1 tare mass 4052 kg

Axle 2 trye size 275/70R 22.5

Axle 2 tare mass 6190kg

Axle 3 tyre size 355/ 50R 22.5

Axle 3 tare 4625kg

Number of passengers Total 102 84 seated & 18 standing

LB

Axle 1 tyre size 275/70R 22.5

Axle 1 tare 3913kg

Axle 2 tyre size 275/ 70R 22.5

Axle 2 tare 4467kg

Axle 3 tyre size 275/70R 22.5

Axle 3 tare 2978kg

Number of passengers Total 75 44 seated & 31 standing

Regards

Paul

Bruce

More data. Just waiting for data for 3 axle DD buses from another operator that is likely to be operating on a permit. The LV looks like it will be operating under the standard axle mass.

LV Bus

Axle 1 tyre size	265/70 R 19.5
Axle 1 Tare mass	1710KGS
Axle 2 tyre size	265/70 R 19.5
Axle 2 Tare mass	2204
Axle 3 tyre size	265/70 R 19.5
Axle 3 Tare mass	3914
Number of passengers max	83 (45 SEATED)

DD Bus

Axle 1 tyre size	355/50R22.5
Axle 1 Tare mass	4240KGS
Axle 2 tyre size	275/70R/22.5
Axle 2 Tare mass	5830KGS
Axle 3 tyre size	355/50R22.5
Axle 3 Tare mass	4858
Number of passengers max	101 (91 SEATED)

Bruce

To date I have only received data for one of the vehicle types of interest. The 2 axle EVDD. The data is below. I am expecting data for 3 axle DD buses and any LV that are intending to operate on an overmass permit. I have followed up the operators again today and will forward the information ASAP.

EVDD Bus

Axle 1 tyre size	355/50 R22.5
Axle 1 Tare mass	4239kg Estimate
Axle 2 tyre size	305/70 R22.5
Axle 2 Tare mass	7886kg Estimate
Number of passengers max	82 passenger (72 seated)

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Napier 4142

20 Dec 2019

Wellington City Council

Transport Assets

113 The Terrace, Wellington

Attention: Pam Brown

Team Leader Data Analysts

Dear Pam

Wellington City 2019 Pavement Model

This is a summary of the 2019 Pavement Modelling Report for Wellington City Council (WCC) to accompany the 2019 excel report sheet.

Regards

[redacted]

Asset Systems Consultant

WSP Napier

Wellington City 2019 Pavement Model

This is a summary of the 2019 Pavement Modelling Report for Wellington City Council (WCC) to accompany the 2019 excel report sheet (2019Outputs_WellCity_dtims_Run1_v4.xlsx).

General

The 2019 pavement deterioration model output is based on the IDSNZ v6.6 dTIMS pavement template (revised in 2018), which allows One Road Network Classification (ONRC) based Customer Level of Service (CLOS) differentiation to be applied for triggering, unit rates and calibration. This is a minor revision of the template used in 2017 WCC pavement model.

Standard ONRC classes are divided by Urban and Rural (Figure 1) for CLOS in the model for triggering. Treatment triggering with the current model setup is shown in the report sheet. The NZIDS dTIMS model uses RAMM treatment length as a base for analysis. The modelled sealed network length was 689 clkm in 2019.

The 2019 Wellington model investment levels are based on WCC Work category (211,212,214) forecasts for the initial 10 years and then a linear estimate from that point for model purposes.

Optimal Budget	Investment Level	
Very High	M$18.4/a	+20%
High	M$16.8/a	+10%
Normal	M$15.3/a	Base (Normal)
Low	M$13.8/a	-10%
Very Low	M$12.3/a	-20%

The WCC sealed network is 50:50 AC and chipseal (Figure 1) with significant VKT on the higher category urban collector and above.

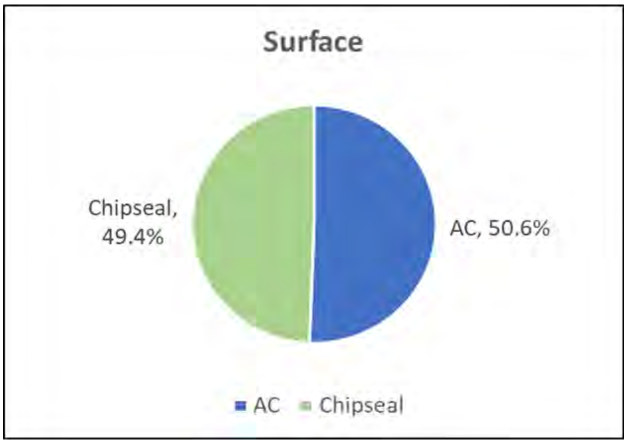
Data

The RAMM extract for the 2019 analysis benefitted from a 100% Rating survey completed in November 2019, which delayed the original timeline but is a significant benefit to the project.

There is some potential for further refinement of the model setup with more time, and more detailed data on the recent bus network changes. The data available for the new bus network configuration is not detailed enough in November 2019 to allow it to be used significantly. As load and pattern data becomes more detailed and particularly as the double decker diesel and electric vehicles are introduced, the ESA impact and load characteristics will be able to be reflected in traffic count and loading data. WCC are working closely with the greater Wellington Regional Council on this and should continue to develop this dataset as the network implementation matures.

Based on the extract from WCC RAMM the data is prepared for the dTIMS model in an interface database where modelling range checks and quality assurance for modelling consistency are performed. This process completes missing or out of range data based on standard NZ model preparation assumptions. For this model additional 5-year historical summary treatment length surfacing and pavement maintenance data was added. Unit rates were current 2019 weighted contract square meter rates from Steve Wright at WCC.

The 2019 forward work programme is limited to the 2109/20 season and is not specified beyond this time. Reporting is not done specifically for the FWP, but it is the fixed first year for all outputs.



Fgroup	ONRC Group	CL_km	%Network
1	High Volume Urban	2.5	0.4%
2	Regional Urban	1.1	0.2%
3	Arterial Urban	110.3	16.0%
4	Primary Collector Urban	119.4	17.3%
5	Secondary Collector Urban	164.0	23.8%
6	Access Urban	159.9	23.2%
7	Low Volume Urban	72.8	10.6%
8	Arterial Rural	7.3	1.1%
9	Primary Collector Rural	18.9	2.7%
10	Secondary Collector Rural	25.1	3.6%
11	Access Rural	7.4	1.1%
		689	100%

Figure 1: Surface Percentage and Network ONRC Grouping

Assumptions on missing historical RAMM pavement dates (95%) were required and the same approach as used in the previous modelling was used. Surface dates were reasonably complete. SNP values were based on the 2014/5 falling weight network survey. Crack calibration was rerun with the new 100% Rating data.

Observations

Model outputs and forecasts will need to be field verified to confirm the programme.

Network Condition:

Wellington City is a high demand predominantly urban sealed network with significant requirement to maintain network availability and minimise maintenance disruption. It has also been adversely impacted by earthquakes in recent years, and higher than normal underground utility disruption. The sealed network is 50:50 Asphaltic Concrete(AC) to chipseal and has some very high demand areas in the top 35% (Primary Collector Urban and above) of the network length (Figure 1). The need to maintain accessibility is a policy impact on timely treatment application.

Rutting does not appear to be a significant issue in the 2019 dataset (Figure 2), with initiation of treatments in the model relative to area cracking and exceeding percentage age (Figure 3) more common. Observed rutting at the 90percentile is not greater than 5mm with Arterial Urban the only ONRC class in this range with minor rut elevation.

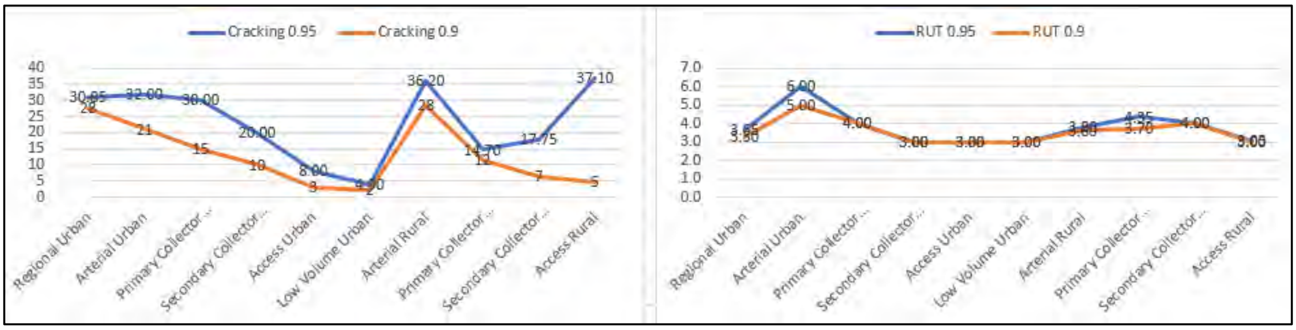


Figure 2: P90 & P95 Crack and Rut Condition by ONRC

The 100% rating data evidenced observations of cracking condition, and there were clearly a reasonable population of cracking at the upper bound percentiles on generally older surfaces, in higher demand areas (Figure 2) in the treatment trigger review. Discussion with the WCC

Transportation Asset staff confirmed that there are older surfaces present that are consistent with this observation which are past optimal treatment timing.

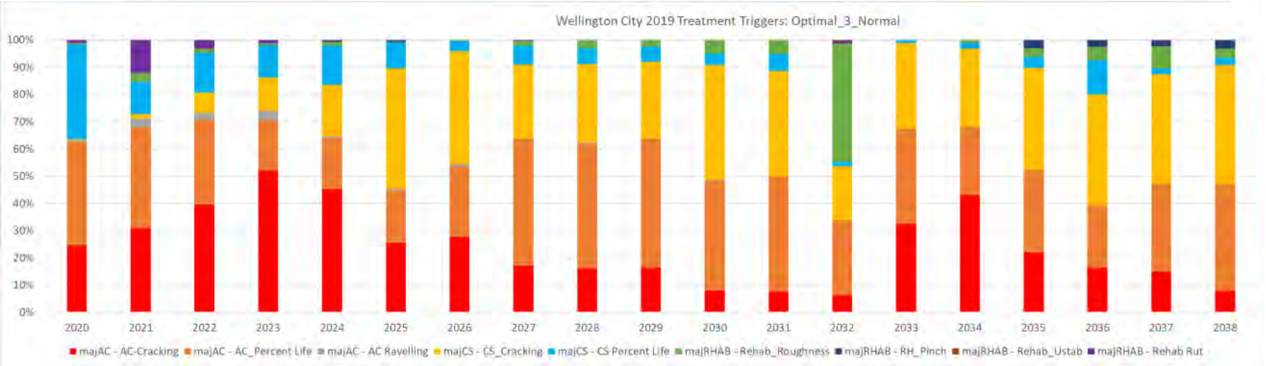


Figure 3: Treatment Triggering in 2019 pavement model

Figure 3 indicates the model triggering for optimal model treatments in the next 20 years being predominantly cracking and aging surfacing in both AC and Chipseal surfacing with some limited rehabilitation. Investment level makes minor changes in the timing, but all optimal investment levels have similar 10-year average annual results as they process current network condition.

The dTIMS model investment level in the first 10 years is expected to be higher than the second 10-year period because of the need to resolve the poor crack condition in high demand areas in the next 5 years (Figure 4). Ideally Surface Integrity Index (SII) should be less than 10 but the 75th percentile (top of the upper blue box) shows a peak in 2023 as the optimal models attempt resolve the older cracked surface condition. Higher demand surfaces are prioritised in optimal programmes so there is a strong focus on AC surfaces which exceed model trigger parameters.

The different levels of optimal investment achieve very similar 10 average figures but the year on year programmes are different according to available investment. High demand sections are a high priority with some condition trade off in lower classification while this occurs. Despite this the roughness (Figure 5) is forecast to be slightly high but stable at a network level.

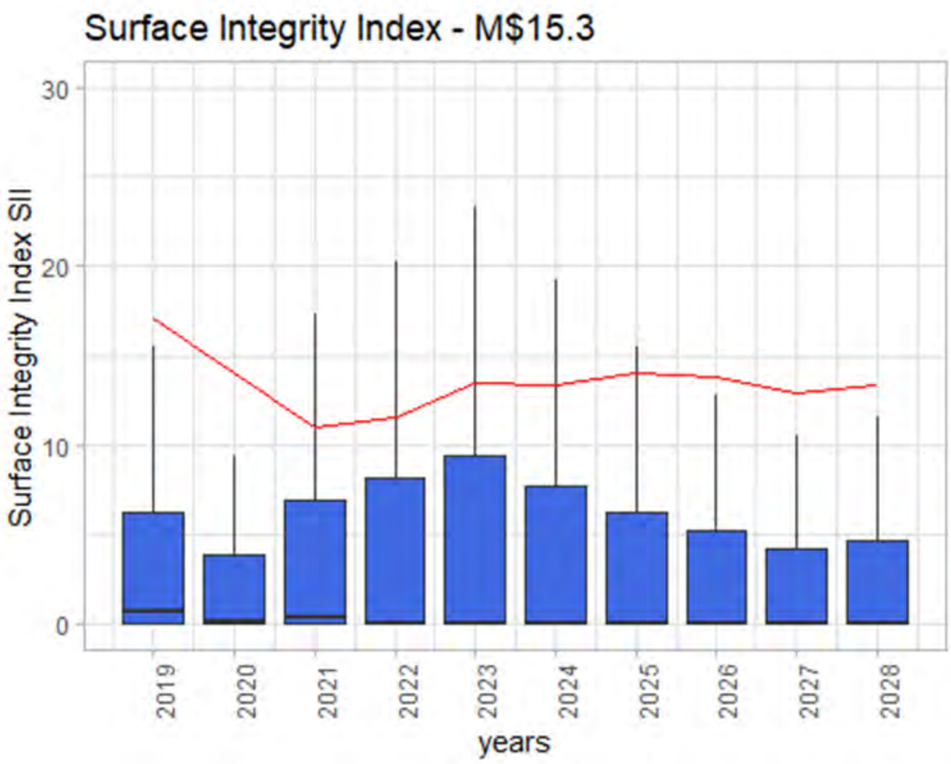


Figure 4: Network Surface Integrity Index M$15.3/a

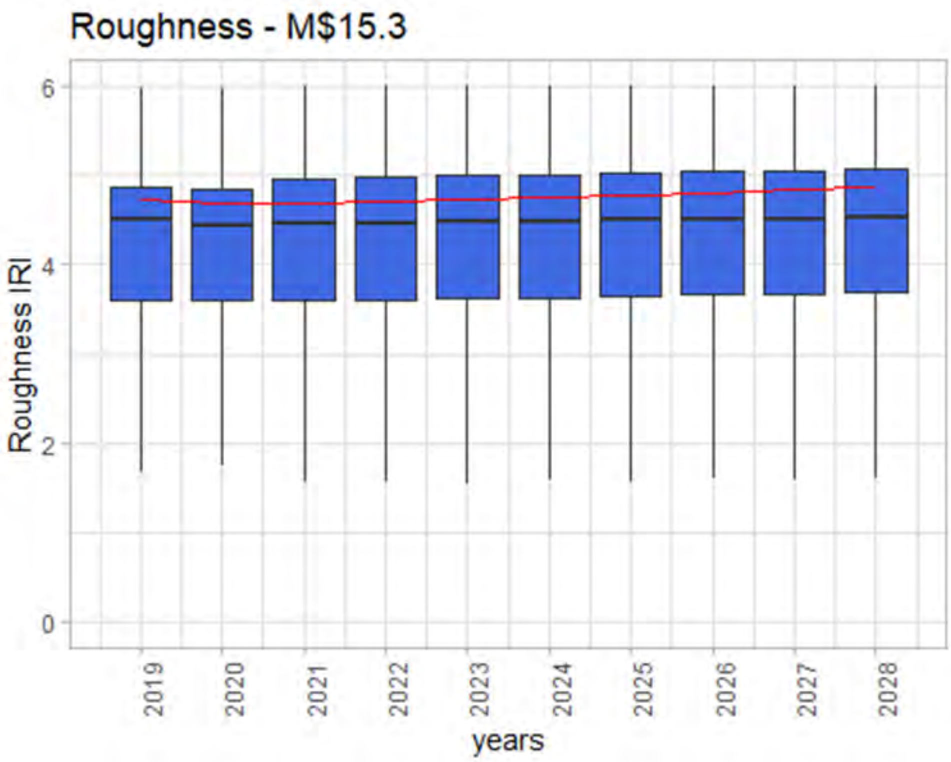


Figure 5: Network Roughness (IRI) 2019-28

Bus Route Changes

The current model setup should be reviewed as the detail of the new GWRC bus routes become more established. The double deck (diesel and electric) configurations being rolled out will generate significant ESA in peak load conditions (over 80 passengers typically depending on vehicle axle configuration). The traffic mix and pattern of peak passenger loading will better characterise pavement impact on the new designated routes. These routes will generally be on secondary collector and above pavements for peak loads, but WCC should continue to utilise available passenger load data from GWRC to identify changing patterns of bus patronage and peak loading (high ESA) so that appropriate pavement maintenance assumptions are applied.

Vehicle loading configurations for the different vehicle configurations need to be reflected in the HCV and traffic mix data so that the pavement and surfacing treatment selection are suitable for peak static and dynamic loadings around bus tops, and regular routes. This is a key area of ongoing data development. Logically the main routes will be higher capacity pavements, but in the distal ends of the routes, peak period loads could require improved pavement capacity and durability for the routes and particularly bus stops in high passenger loading areas.

A review of the ONRC once the new routes are established is also recommended. The new bus network is quite different to the previous one. Any significant change in HCV or bus traffic needs to be incorporated in the traffic composition in RAMM and incorporated in the transport asset plan for future CLOS review.

10-Year Treatment Summary

10-year average annual treatment lengths and costs are summarised in Figure 6. NB: the WCC 2019 model forward Work programme (FWP) is a single year and so should be considered with that limitation. All optimal models have year 1 as this same specified or fixed programme. Optimal models have a higher annual routine maintenance level and constrained planned maintenance based on the CLOS in the model setup. The trigger model (unconstrained investment) does use rehabilitation in urban lengths extensively, but policy wise this is unlikely to be viable in lower classifications with current investment constraints.

Treatment (Network Surf Length)	10 Year Average Summary	Historic Avg (2014-2018)	Optimal Model Outputs M$18.4	Optimal Model Outputs M$15.3	Optimal Model Outputs M$12.3	FWP (1 year)	Trigger Model
CS (340.5km)	km/year	24.4	21.6	21.6	21.6	5.0	27.4
	%/year	*6.3%*	*6.3%*	*6.3%*	*6.3%*	*1.5%*	*8.0%*
	cost/yr($'000)	1950.1	1721.3	1722.5	1721.4	405.1	2201.1
AC (348.6km)	km/year	19.7	23.9	23.9	23.8	2.0	22.9
	%/year	*4.4%*	*6.8%*	*6.8%*	*6.8%*	*0.6%*	*6.6%*
	cost/yr($'000)	6063.1	7352.4	7354.4	7346.8	566.4	7237.1
REHAB (689.2km)	km/year	1.68	1.07	1.05	1.05	1.07	9.60
	%/year	*0.7%*	*0.2%*	*0.2%*	*0.2%*	*0.2%*	*1.4%*
	cost/yr($'000)	743.3	473.7	465.6	465.6	76.6	3740.0
Total Surfacing Investment ($'000)		8013.3	**9,074**	**9,077**	**9,068**	**972**	**9,438**
Total Pavement Investment ($'000)		743.3	**474**	**466**	**466**	**77**	**3,740**
Total Investment ($'000)		8756.6	**9,547**	**9,543**	**9,534**	**1,048**	**13,178**
		* based on current Ave$/km				**Only 1 year**	

Figure 6: 10-year Average Annual Treatment Summary

Rehabilitation

Current optimal forecasts with the current CLOS include a small amount rehabilitation in the initial 5 years with a focus on higher demand ONRC (Figure 8). Model deterioration forecasts in the 2030 decade show some rehabilitation for lower category lengths based on terminal roughness, and the onset of rutting and surface instability sufficient to trigger rehabilitation treatments. Investment level has minor variation in the optimal outputs rehabilitation forecast, other than minor treatment timing.

Rutting is generally low and reliant on model deterioration to generate over time. Managing cracking on aging surfaces is the main asset management task in the next 5-year period. Once the higher demand AC surfaces are contained there will be a shift to cracked chipseal surfacing to manage on top of the reduced AC cracking with minor rehabilitation on current model forecasts.

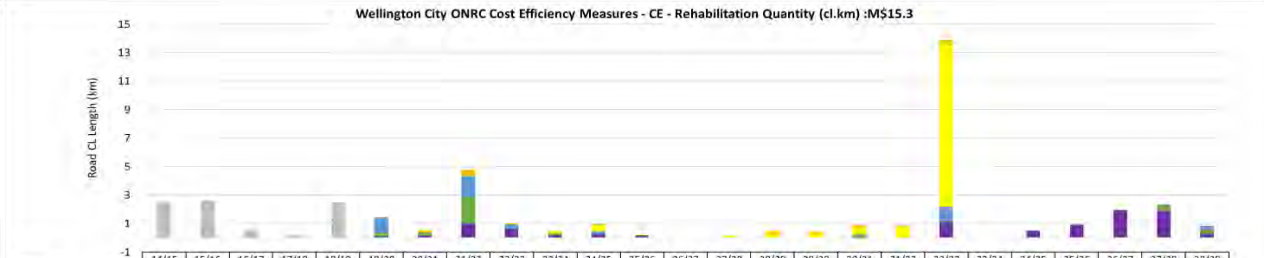
As with previous modelling observation, data support for rehabilitation selection needs to be refined. In higher demand areas AC is a likely to be a 'defacto' rehabilitation alternative if the pavement is not compromised by delayed treatment. In some situations, delayed treatment is constrained by planned major or utility projects, so condition degradation is a short-term compromise. As forecast investment drops in the late 2020's there may be potential to consider some strategic rehabilitation length to spread risk in the collectors and access urban to allow more programme flexibility as the significant pavement lengths in that classification. Higher capacity buses are also likely to be more common on those lengths in future years.

Forecast rehabilitation at 1-2km/a is 0.2% of the network length, and the last 5 years 1.7km/a. To put this in perspective a nominal pavement by ONRC estimation table is shown in Figure 7. Assuming a nominal pavement life allocation by ONRC, the average rehabilitation length (by ONRC per year) can be derived, and a nominal annual rehabilitation length derived. With the assumption below this would be 12.4km/a or 1.8% of the network length.

ONRC	Regional Urban	Arterial Urban	Primary Collector Urban	Secondary Collector Urban	Access Urban	Low Volume Urban	Arterial Rural	Primary Collector Rural	Secondary Collector Rural	Access Rural	Network Length		
REHAB Length (clkm)	0.64	105.11	78.27	216.32	145.57	84.69	2.24	5.53	36.65	14.16	689.17		
Indicative Pavement Life (Yrs)	25	35	45	50	100	120	35	50	50	60	57	1.8%	REHAB % Network Length
REHAB Required (km/annum)	0.03	3.00	1.74	4.33	1.46	0.71	0.06	0.11	0.73	0.24	12.40	Est Rehab (km)/Year	

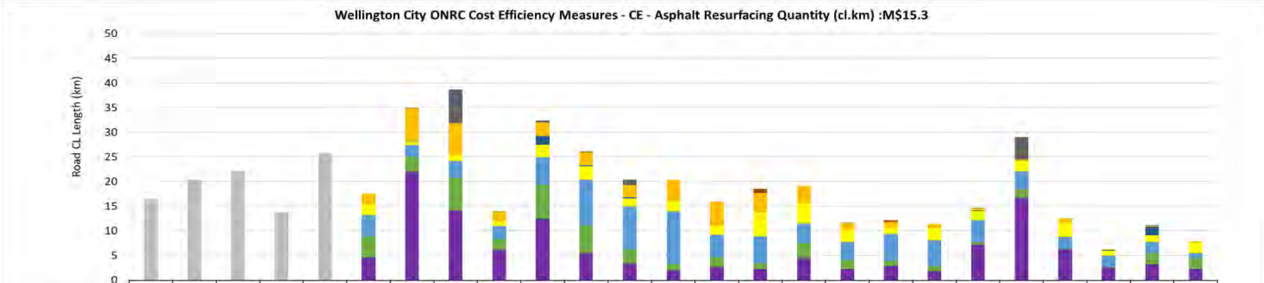
Figure 7: Rehabilitation Estimate Comparison

Figure 8, Figure 9 and Figure 10 show the rehabilitation, AC and chipseal forecast for the M$15.3 optimal model with the break down by year and ONRC.



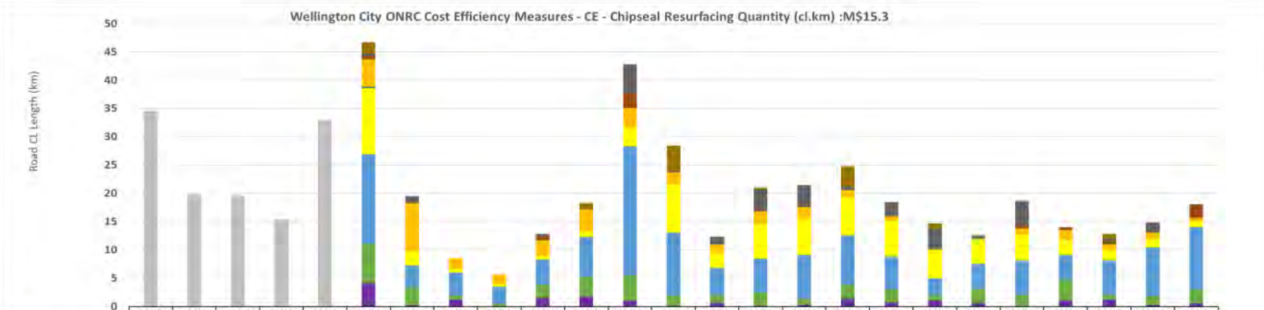
	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	24/25	25/26	26/27	27/28	28/29	29/30	30/31	31/32	32/33	33/34	34/35	35/36	36/37	37/38	38/39
Historic	2.5	2.6	0.6	0.2	2.5																				
Low Volume Urban						0.0	0.2	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Access Urban						0.0	0.0	0.0	0.0	0.1	0.5	0.0	0.1	0.1	0.3	0.3	0.4	0.7	11.3	0.0	0.0	0.0	0.0	0.0	0.0
Secondary Collector Urban						1.1	0.0	1.5	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.3
Primary Collector Urban						0.2	0.2	1.9	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.5	0.3
Arterial Urban						0.1	0.2	1.0	0.6	0.2	0.3	0.2	0.0	0.0	0.0	0.0	0.1	0.0	1.1	0.0	0.5	0.9	1.9	1.8	0.3

Figure 8: Rehabilitation by ONRC with M$15.3 Investment



	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	24/25	25/26	26/27	27/28	28/29	29/30	30/31	31/32	32/33	33/34	34/35	35/36	36/37	37/38	38/39
Historic	16.4	20.3	22.1	13.8	25.8																				
Access Rural						0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Secondary Collector Rural						0.0	0.1	6.8	0.0	0.4	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	4.6	0.0	0.0	0.2	0.0
Primary Collector Rural						0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low Volume Urban						2.3	6.7	6.4	2.0	2.7	2.6	3.4	4.5	4.9	3.9	3.5	1.5	1.1	0.9	0.5	0.2	1.0	0.0	0.1	0.3
Arterial Rural						0.0	0.1	0.0	0.0	1.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.2	1.8	0.0
Access Urban						2.1	0.7	1.2	0.9	2.5	2.7	1.6	2.0	1.8	4.9	4.1	3.3	1.4	2.5	1.9	2.2	2.8	1.0	1.3	2.2
Secondary Collector Urban						4.3	2.3	3.5	2.6	5.6	9.2	8.8	10.6	4.5	5.4	4.0	3.7	5.4	5.2	4.4	3.6	2.4	2.2	2.3	1.0
Primary Collector Urban						4.2	3.0	6.6	2.2	6.8	5.7	2.8	1.3	2.0	1.2	3.1	1.8	1.1	1.0	0.5	1.7	0.1	0.2	2.4	2.2
Arterial Urban						4.6	21.9	13.7	6.1	12.5	5.4	3.3	1.9	2.7	2.3	4.4	2.3	2.8	1.7	7.1	16.5	6.2	2.5	3.1	2.2
Regional Urban						0.0	0.2	0.4	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.1	0.0	0.1	0.0

Figure 9: AC by ONRC with M$15.3 Investment



	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	24/25	25/26	26/27	27/28	28/29	29/30	30/31	31/32	32/33	33/34	34/35	35/36	36/37	37/38	38/39
Historic	34.6	19.7	19.5	15.4	32.9																				
Access Rural						2.0	0.0	0.0	0.0	0.0	1.0	0.0	4.5	0.0	0.4	0.0	3.5	0.0	3.0	0.0	0.0	0.0	0.9	0.0	0.0
Secondary Collector Rural						0.5	1.2	0.0	0.0	0.6	0.0	5.1	0.2	1.3	3.8	4.0	0.7	2.4	3.5	0.5	4.3	0.1	0.3	1.7	0.2
Primary Collector Rural						0.5	0.0	0.0	0.0	0.6	0.1	2.5	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.5	0.4	0.6	0.0	2.2
Low Volume Urban						4.9	8.6	1.9	1.6	2.7	3.9	3.5	2.1	1.5	2.2	2.0	1.3	0.8	0.2	0.3	1.2	1.8	1.0	1.1	0.6
Arterial Rural						0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Access Urban						11.7	2.4	0.7	0.5	0.7	1.1	3.3	8.6	2.7	6.2	6.5	6.8	6.4	5.0	4.2	4.5	2.7	1.9	1.6	1.0
Secondary Collector Urban						15.7	4.0	4.0	3.0	4.4	7.0	22.8	11.1	4.6	5.9	7.7	8.6	5.8	3.0	4.4	6.2	4.3	6.1	8.6	11.0
Primary Collector Urban						7.1	3.1	0.7	0.5	2.4	3.5	4.5	3.8	1.3	2.3	3.1	2.5	2.3	3.0	2.5	1.9	3.6	0.9	1.5	2.5
Arterial Urban						4.1	0.2	1.2	0.0	1.5	1.8	1.0	0.1	0.7	0.1	0.3	1.4	0.7	1.0	0.6	0.0	1.1	1.2	0.3	0.5
Regional Urban																									

Figure 10: Chipseal by ONRC with M$15.3 Investment

Regular pavement condition data to validate asset condition and to ensure that any network demand changes can be assessed for deterioration impact is good practice in road asset management. Review of representative pavement sections (5-10%) of the network with a pavement evaluation tool (Falling weight deflectometer (FWD) or multispeed deflectometer (MSD)) is recommended to ensure pavement life assumptions are reasonable with changes in network demand, and basic deterioration. This would be in addition to normal surface condition surveys like rating and roughness.

This ongoing review would add confidence to the whole of life asset management assumptions for the WCC pavement assets and build on the 2014/15 Full FWD survey and verify condition assumptions. The impact of specific utility disruption/remediation and delays in treatment may also be able to be better understood for longer term management impact.

AC

Year 1-10 averages for the Optimal programmes are very similar and are consistent with historical lengths. Initial priority is on arterial urban, primary collector urban, and secondary collector urban based on percent surface age and crack condition (Figure 3). Optimal model AC forecasts (Figure 9) are all elevated in the initial 6 years and stabilise to a lower level after 2030 where demand is balanced across ONRC classes with the current model CLOS settings. All programmes move to more secondary collector and lower urban classes through to the mid-2030s when arterial urban again increases. While not as high a priority the lower class are a significant length in the network. Given the higher square metre rate for AC over chipseal there is economic tension on treatment selection in these lower classifications.

Arterial urban (24% of total AC length) and secondary collector urban (30% of total AC length) are well represented through the analysis period. Clearly major projects and utility disruption can delay treatments in the main city urban areas, so some timing delay is a practical programme management reality, and this will have level of service implications which are part of the overall asset management story for the WCC network. 60% of network AC is in urban secondary collector/access/low volume lengths, so the potential for older surfaces increases, particularly access urban. Field review and policy on managing older AC surfaces needs to be maintained in these lower classification areas of the network.

The Trigger programme (no investment constraint) does any condition driven remedial work in year 2 (2020) and has a similar general ONRC mix. NB: The unlimited investment characteristic of the trigger model means it has no financial limit and triggers only on condition with no other limitation or CLOS constraint. It is a comparative tool to assess potential condition liability in the network and not an economic or policy constrained outcome.

Chipseal

Figure 10 shows the resurfacing by year and ONRC for the M$15.5 optimal output. There is some timing impact as the high classification condition is prioritised with AC investment to 2024/25, but there is a clear priority on urban secondary collector, access, low volume and rural secondary collector lengths in the resurfacing programmes. Triggering is initially percent surface age in the first 3 years with cracking then forecast to become the main trigger for chipseals (Figure 3). Surface life is regularly reviewed by WCC and the resurfacing programme is based on regular field observation and condition rating, so the model CLOS assumptions should be reasonably well informed.

Chipseal resurfacing is slightly reduced in the 10-year forecasts, and this may reflect the general reduced CLOS requirements in the lower ONRC classes where it is most likely to be applied, i.e. they can get rougher for longer.

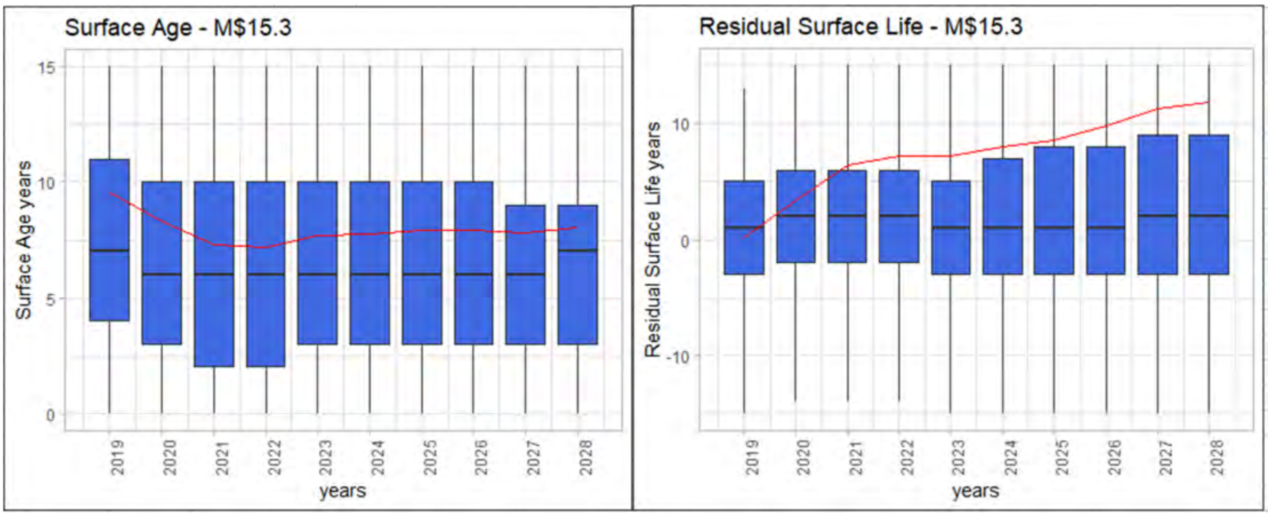


Figure 11: 10 -Year Network Surface Age and Surface Life (M$15.3)

Surface age 75th percentiles (top of blue box in Figure 11) show a minor drop over the first 10 years, with a slight increase in residual surface life. There are clearly still older surfaces (negative residual) in the population but the programme has the 75th percentile increasing to be able to manage this if required. Network roughness (Figure 5) does show a slight 75th percentile increase in the 10-year forecast but is generally stable. The nature of the WCC network does have significant areas of hill suburbs where geometric constraints make smooth surface management challenging, so this is a good result. There may be some potential to programme additional resurfacing in the programme from 2025 if the CLOS is not being achieved.

Investment Level

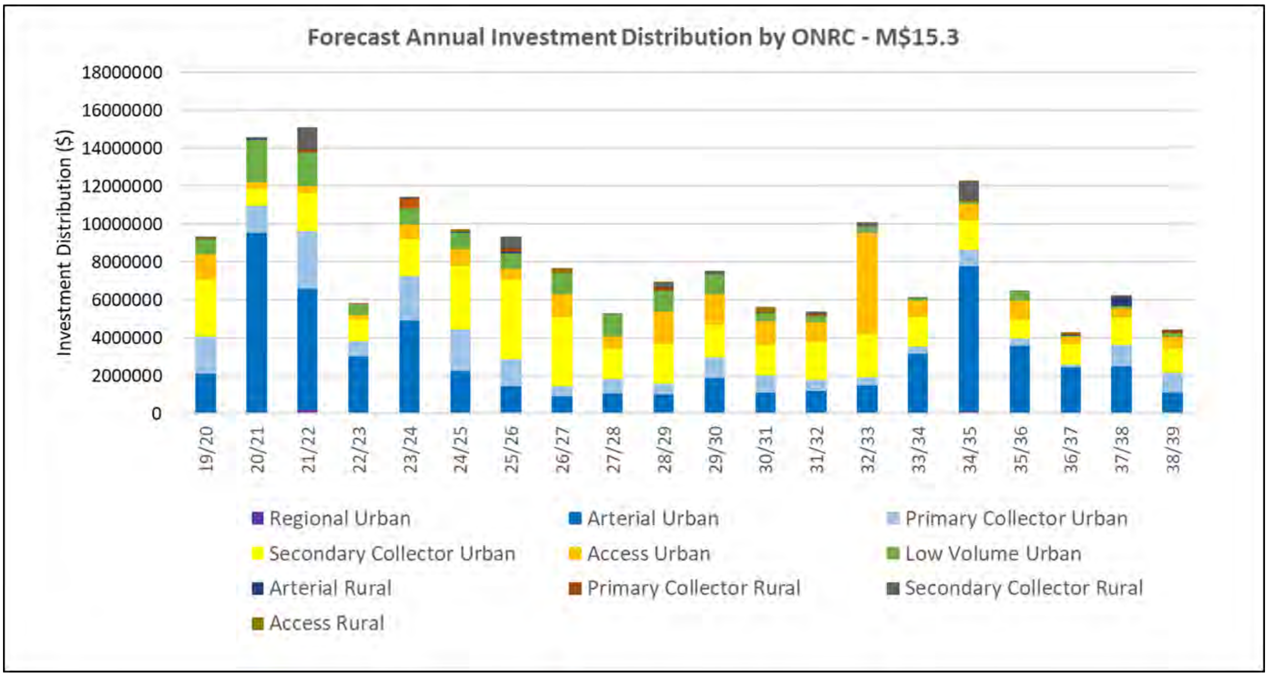


Figure 12: Investment Distribution by Year and ONRC

Figure 12 has the 20-Year investment forecast (planned AC/CS/Rehabilitation) which indicates a period of higher investment to 2025 and a period of lower annual investment to 2032-35. Current work category estimates are sufficient to maintain the current CLOS set in the 2019 pavement deterioration model.

As noted previously there is not any specific impact of the revised GWRC bus routes in the current analysis. As the routes are matured and the intended heavier double decker vehicle configurations implemented there will need to be some revision of CLOS on areas with the new routes, particularly lower classification pavements.

There is also some natural risk to any investment programme in Wellington as the timing of treatments is often impacted by capital projects, external and non-transportation utility planning requirements which can delay and disrupt the planned road asset maintenance programme. Given the high demand on the road transport network in the region there is a need to have some greater flexibility to deal with programme change, and to have network availability as a criterion over condition at times given the need to work in with no transport infrastructure programmes.

Data Improvement

- The model is limited in terms of the estimated nature of most WCC pavement dates. Age based rehabilitation triggering is impacted by this, as is the calibration based on pavement age. This is an area of general improvement which could improve rehabilitation forecasts, and to the asset risk assessment in the future.
- Additionally, there does need to be a programme of pavement testing on representative pavement sections on an annual basis to build on the 2014/15 FWD testing to determine any pavement deterioration characteristics. This would also be useful in assessing changes to traffic loading in key areas due to changes in use (e.g. project impact, bus route or vehicle type changes). A targeted FWD or MSD programme on 5-10% of the network determined by changes and risk assessment would better inform the remaining life assessment, and identify any areas requiring more (or less) review.
- Current surface data collection should be continued, particularly where lengths are delayed treatments or older than the expected surface life.

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IDS

Assessment of pavement impacts associated with increased bus axle loads on the Wellington City road network - 2020 update

July 2021

Assessment of pavement impacts associated with increased bus axle loads on the Wellington City road network - 2020 Update

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Quality Assurance Statement		
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	Reviewed by:	[redacted]
	Approved for issue by:	[redacted]

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A	[redacted]	Draft for review	12/07/2021
1	[redacted]	Final	19/07/2021
2	[redacted]	Final for issue	21/07/2021

Executive Summary

In late 2017 Greater Wellington Regional Council (GWRC) embarked on a programme to improve public transport in the region which includes the replacement of trolley buses in their bus fleet with a number of high-capacity urban buses (Diesel (DDD) and Electric Double Decker buses (EVDD)). These new double decker buses are operating at axle masses that are greater than the allowable axle masses for general access as defined in the Vehicle Dimensions and Mass Rule (VDAM) when a certain passenger number is exceed.

The introduction of these buses is likely to cause increased pavement wear on the Wellington City Council (WCC) road network depending on the type of bus and the routes followed. WCC has attempted to quantify the potential increase in road maintenance costs since the introduction of the new buses in 2018.

The primary objective of this study is to assess the additional pavement wear-related costs that could be attributed to an increase in the axle mass for the high-capacity urban buses on the WCC road network. This report summarises the results from the analysis based on historic pavement and surfacing maintenance cost on the network, and selected bus axle and load configurations.

For the purpose of this study, the cost of additional pavement wear due to the new electric and diesel double decker buses is defined as the cost of pavement wear that occurs when a vehicle is estimated to be operating with axle masses that are greater than the allowable axle masses for General Access (GA) as defined in the VDAM Rule.

It is expected that more of these high-capacity urban buses will be introduced to the bus fleet over a period of time dictated by demand. Such demand may also result in certain routes carrying increased number of passengers which will affect the loading and pavement wear costs. This provides the opportunity to update the report in following years with updated passenger numbers and maintenance costs.

Study progression

Prior to this current study IDS carried out two earlier studies for WCC using its pavement damage calculation tool to estimate the costs associated with the new bus fleet. The study completed for the 2017 period used assumed values for load distribution between bus axles and bus occupancy and bus frequency/numbers to assess the expected additional maintenance costs associated with the heavier buses on the network. The subsequent study completed for 2019 used the initial bus loading data from the on-board ticketing system. Analysis of this data showed that the loading distributions were significantly different to those assumed for the previous study and the roll-out/implementation of the DDD and EVDD buses was slower than assumed. The maintenance cost data set was the same for both studies.

The current study (2020 update) is the first study that uses actual 12-month passenger data from GWRC for the period for the analysis period Jul 2019 – Jun 2020. This study also used an updated set of maintenance cost data from the WCC RAMM Contractor database for the past 5 years (2016 – 2020).

Estimated additional costs

The estimated additional pavement maintenance costs per year as a result of operating Diesel Double Decker buses (DDD) and Electric Double Decker buses (EVDD) above the GA mass limits are:

DDD	$27,355
EVDD	$97,515
Total Additional Cost (per year)	**$124,870**

The maintenance cost on the bus routes for the 2016 – 2020 period is higher than for the 2012 – 2016 period. From the data it appears as if the quality of record keeping of maintenance cost items has improved significantly. The increase in maintenance costs may also be attributed to a real increase in maintenance being carried out on these routes.

The 2020 bus loading distributions were lower compared to the earlier studies. This is likely due to the analysis period (July 2019 – June 2020) coinciding with the COVID-19 lockdown period which included an approximately 7-week lockdown period between March and May 2020.

The ratio of pavement wear costs between the DDD and EVDD vehicles is approximately 1 to 4 which is comparable to the distances travelled above the GA limits by each of these vehicles.

The additional cost calculated for the period July 2019 to June 2020 lies between the 2017 and 2019 estimates of $166,750 and $58,645 respectively. The expected increase is approximately 1.1% of the annual maintenance cost for the bus routes and the impact is lower than what other stakeholders may expect. The 2020 result is considered more reliable as it is based on actual passenger data for the period under consideration and updated pavement maintenance costs.

Contents

Definitions and 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
BVKT	Bus kilometres travelled. The length of a road section multiplied by the number of buses using it
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
DDD	Three axle Diesel Double Decker Bus
ESA	Equivalent Standard Axle. Single axle with dual wheels loaded to a total mass of 8.2 tonnes and 750 kPa tyre pressure used as a means of normalising different axle weights and configurations loads to allow an estimate of the relative damage caused
EVDD	Two axle Electric Vehicle Double Decker Bus
GA	General Access. A vehicle that can operate without a permit, subject to any specific route or bridge restrictions
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 mass
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
HCUB	High Capacity Urban Bus. A heavy passenger service vehicle fitted with seating positions for 60 or more passengers that is operating in a public transport service that is identified in or under a regional public transport plan as defined in the Land Transport Management Act 2003
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
LV	Three-axle Large passenger vehicle (83 passengers)
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 mass at normal highway speeds, count and classify vehicles numbers

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

1. Introduction

1.1 Background

In late 2017 the Greater Wellington Regional Council (GWRC) embarked on a programme to improve public transport in the region which included the replacement of trolley buses in their bus fleet with a number of high capacity urban buses (HCUB). One of the reasons for the introduction of the HCUBs to the network was to reduce the bus congestion in the CBD area.

In 2010 NZTA introduced a new class of heavy vehicle called a High Productivity Motor Vehicle (HPMV). These vehicles can operate with masses or dimensions greater than that permitted for an ordinary (General Access (GA)) heavy vehicle. A HPMV can be granted a permit to operate with higher axle masses (up to a specified maximum) either over a specified route or a general area as determined by the Road Controlling Authority (RCA), WCC in the case. In 2016 the Vehicle Dimensions and Mass Rule (VDAM) was amended to create a Specialist Vehicle category that includes passenger service vehicles. This amendment allowed specialist vehicles to operate under a permit with axle masses that are greater than those allowed for GA and HPMV vehicles.

The new GWRC bus fleet comprises of a combination of Diesel (DDD) and Electric Double Decker buses (EVDD) and vehicles from the current fleet (excluding trolley buses). These new buses will be operating at axle masses that are greater than the allowable axle masses for General Access (GA) as defined under the VDAM Rule and therefore will require a specialist vehicle permit to enable the buses to be able to carry the maximum number of passengers that they have been designed to carry.

It is expected that more of these HCUBs will be introduced to the bus fleet over a period of time as the expected demand for public transport increases. This fleet will continue to use the current bus routes on the WCC road network.

1.2 Problem statement

The replacement of the trolley buses with a newly configured bus fleet, which included high capacity urban buses, is likely to cause increased pavement wear on the WCC road network depending on the type of bus and the routes followed. Although these vehicles operate under permit, the magnitude of the pavement damage caused is yet to be fully quantified. WCC has attempted to quantify the potential increase in road maintenance costs since the introduction of the new buses in 2018.

1.3 Study progression

In 2018, prior to the implementation of the new bus fleet, WCC initiated a study to determine the estimated pavement related costs associated with the heavier bus fleet. This IDS study relied on estimated passenger loadings on these new buses and maintenance cost records on the bus routes that were available from the Council's RAMM Contractor platform for the 5 years prior to the study i.e. 2012 – 2016. The assessment focussed on the additional cost in year 1 of the bus fleet operating under the current numbers as agreed with GWRC and WCC. This approach provided the opportunity to update the report in following years with actual passenger numbers and updated maintenance costs.

When actual passenger data became available in 2019 a follow-up study was undertaken by IDS to update the estimated loading in the 2017 study. This study used passenger data for the bus operations between 1 March

2019 and 31 July 2019 and scaled up to 12 months. Maintenance costs and pavement condition were assumed to be the same as for the 2017 study.

The current study (2020 update) is the first study that uses actual 12-month passenger data from the on-board ticketing system which was obtained from GWRC for the period July 2019 to June 2020. An updated set of maintenance cost data was also obtained from WCC RAMM Contractor database for the past 5 years i.e. 2016 – 2020 to calculate the pavement wear-related costs on the network.

1.4 Study objective and scope

The primary objective of this study is to assess the additional pavement wear-related costs that could be attributed to an increase in the axle masses for urban buses on the WCC road network.

The pavement impacts from buses with a range of axle combinations and masses that covers the re-configured bus fleet on the GWRC-defined bus routes were assessed using the IDS pavement wear cost estimation model. This report summarises the results from the analysis based on pavement and surfacing maintenance cost on the network, and selected bus axle and load configurations.

For the purposes of this study, the cost of additional pavement wear due to the new Diesel Double Decker (DDD) buses and Electric Double Decker (EVDD) buses is defined as the cost of pavement wear that occurs when a vehicle is estimated to be operating with axle masses that are greater than the allowable axle masses for General Access (GA) as defined in the VDAM Rule. The cost of the pavement wear caused by any heavy vehicle that is operating under the GA limits is assumed to be included in the existing road maintenance budget.

1.5 Exclusions

No physical pavement testing was undertaken on the proposed bus routes. The study relies on work completed by Geosolve in a 2015 in which the WCC road network was categorised according to the remaining life of each treatment length.

This study does not include cost impact assessment on bridge structures and current State Highway sections within the WCC network.

2. Vehicle loading and movements

2.1 Vehicle Dimension and Mass Rule (VDAM)

The legislated vehicle and mass limits in New Zealand are outlined in *The Land Transport Rule: Vehicle Dimensions and Mass 2016 Rule* 41001/2016 (VDAM), which came into force on 1 February 2017. This rule outlines the vehicle mass limits for *Public Service Vehicles* applicable to this study and can be summarised as follows:

Table 2-1 General Access Mass Limits for Public Service Vehicles (Buses)

Maximum mass on individual axles		
Single standard tyres	In a tandem axle set with twin-tyred axle	5,800kg
	In any other axle set	6,000kg
Twin tyred	In a tandem axle set with single standard-tyred axle	8,700kg
	In any other axle set	8,200kg* (9,000kg from 1/12/2018)
Maximum total mass on two axles in a tandem set		
Twin tyred axle	With a single standard-tyred axle and load share of 60/40	14,500kg
	With a single standard-tyred axle or single mega-tyred axle and load share between 60/40 and 55/45	14,500kg
Maximum total mass	Length between 8m and 14m	Between 30,000kg and 40,000kg

Table 2-2 Specialist Vehicle Mass Limits for Public Service Vehicles (Buses)

Maximum mass on individual axles		
Single large tyre	In a tandem axle set with twin-tyred axle and a 55/45 load share	8,100kg
Twin tyred	In any axle set	12,000kg
Maximum total mass on two axles in a tandem set		
Twin tyred axle	With a single large-tyred axle and load share of 60/40	16,000kg
	With a single large-tyred axle and load share of 55/45	18,000kg
Maximum total mass	Length between 8m and 14m	Between 34,000kg and 45,000kg

This rule allows for heavy vehicles to operate under permit at sizes and weights above the standard legal maxima on approved roads within New Zealand.

2.2 GWRC bus details

The bus fleet used on the WCC network comprises a range of makes and models. Data on the buses of interest (EVDD and DDD) was supplied by GWRC and summarised in Table 2-3.

Table 2-3 HCUB details

Bus	Axle Design Mass			Number of passengers at 100% loading	Number of passengers when rear axle exceeds GA limits
	Front	Rear	Total		
DDD 3-axles	7,120kg	15,888kg	23,008kg	101	82 @ 14,500kg
EVDD 2-axles	6,760kg	11,950kg	18,710kg	82	36 @ 8,200kg (42 @ 9,000kg from1/12/2018)

2.3 Definition of this study

For the purposes of this study, the cost of additional pavement wear due to the new electric and diesel double decker buses is defined as the cost of pavement wear that occurs when a vehicle is estimated to be operating with axle masses that are greater than the allowable axle masses for General Access (GA) as defined in the VDAM Rule.

3. Model development

IDS has developed a model that allows the cost, in terms of pavement wear, to be calculated for a specific vehicle travelling over a specified route. The cost is calculated by considering the historical maintenance costs, historical heavy vehicle volumes, current pavement strength and proposed vehicle configurations and usage. The model is scalable from a single vehicle on a specific route to a fleet operating over a network.

The IDS pavement wear cost estimation model requires five inputs:

1. A defined network (the *network*)
2. Annual Maintenance cost for the network
3. Distribution of the pavement strength or remaining life of the network
4. Annual HVKT for the network
5. Details of the proposed HCV that will be used on the network including axle/load configurations and proposed HVKT.

For this study, the cost of a specific bus (DDD or EVDD) travelling on a specific route was calculated for a number of different HCUBs operating on various routes.

3.1 A defined network (the *network*)

The datasets available to this study had sufficient detail to allow each route of the proposed bus network to be modelled as a separate network.

The RAMM carriageway sections on the proposed bus routes were grouped into CBD, north and south segments for each proposed route. This enabled a hub (CBD) and spoke (north or south segment) network model to be created. Only roads that are owned by the WCC are included in the model, i.e. State Highways are excluded from the analysis.

3.2 Annual maintenance cost for the network

WCC provided all the individual maintenance activities and claimed costs for the bus routes for the previous 5 years i.e. 2016 - 2020. This information is captured in the RAMM Contractor platform where each contractor claim resulting from a maintenance activity is allocated to the relevant RAMM carriageway section.

This information is considered comprehensive as the network Maintenance Contractor is required to track and claim its maintenance activities in the RAMM Contractor environment. For this study the actual claim costs were increased by 25% to cover the fixed contract and WCC administration costs.

The annual maintenance cost for each spoke was calculated using the network and cost datasets associated with each spoke as described above. This customised annual cost was used as the annual maintenance cost input for the cost calculator spreadsheet.

A comparative summary of maintenance records is shown below:

Table 3-1 Maintenance cost record summary

Study date	Total maintenance cost spend (annual)[1]	Annual maintenance cost for DDD & EVDD bus routes[1]
2012 – 2016	$68M ($13.6M)	$3.38M
2016 – 2020	$85M ($17.1M)	$11.6M

[1] These costs include WCC (10%) and Contractor overheads (15%)

The 2012 – 2016 study reviewed 1900 carriageway sections which had maintenance cost logged against them, a total of 8772 line items compared to the 2016 - 2020 study which had 3675 carriageway sections with maintenance costs against them, a total of 18480 line items.

This summary shows that the annual maintenance costs for the bus routes for the 2016 – 2020 period is more than three times that of the 2012 – 2016 period. In addition, the number of line items with pavement related maintenance costs items are more than double those reviewed in the previous (2019) study. We also noticed that in the 2019 study 226 of the 479 carriageway sections on the bus routes had no maintenance cost compared to the 2020 study in which only 34 carriageway sections had no maintenance cost.

The higher maintenance costs recorded on the bus routes over the past 5 years compared to the previous years are due to either improved record keeping or a real increase in maintenance being carried out on these routes.

3.3 Distribution of pavement strength or remaining life of the network

The cost calculator requires the distribution of the remaining life of the pavement for the network under consideration to be allocated into six categories. For this project the allocation was based on work completed by Geosolve which allocated a remaining life to each RAMM treatment length section based on an FWD survey of the network in 2015. There were a number of sections that did not have a Geosolve rating, these sections were allocated a remaining life value based on the spread of the remaining life values of sections in that network/route under consideration.

3.4 Annual HVKT for the network

The total HVKT for each spoke was calculated by using the HVKT data contained in the RAMM dataset. Each carriageway section in the RAMM dataset has a HVKT value assigned to it which is the product of the AADT, carriageway length and percentage of HCV. For each spoke, the HVKT values for each carriageway section were summed to give the HVKT total for the spoke. The HVKT remained unchanged from the 2019 study.

Bus volumes as a percentage of total HCV range from 9 to 44%.

3.5 Details of the re-configured bus fleet loading

The buses of interest to this study are the three axle Diesel Double Decker Buses (DDD) and two axle Electric Vehicle Double Decker Buses (EVDD).

3.5.1 Bus VKT

GWRC provided passenger data for the bus operations between 01 March 2019 and 31 July 2019. This passenger data was used to update the estimated loading in the previous model. The total BVKT over this period was used and was prorated up to 12 months based on the information provided i.e. all bus trips were considered in the analysis and not just peak hour trips per the 2017 study. The total BVKT used in the analysis is summarised below.

Table 3-2 Total BVKT

Vehicle	Route	Zone	BVKT (Mar to July 2019)	BVKT per year
DDD	**1**	CBD	76,074	182,577
		Northern	108,964	261,513
		Southern	56,767	136,241
	3	CBD	26,183	62,839
		Southern	52,817	126,761
	7	CBD	13,598	32,635
		Southern	20,183	48,440
	36	CBD	1,701	4,082
		Southern	3,906	9,375
	56	CBD	2,554	6,129
		Northern	3,690	8,855
	57	CBD	4,311	10,347
		Northern	5,640	13,536
	58	CBD	3,056	7,334
		Northern	4,344	10,426
	23e	CBD	4,410	10,584
		Southern	6,137	14,729
	31x	CBD	3,791	9,099
		Southern	5,024	12,058
	32x	CBD	7,961	19,107
		Southern	9,497	22,794
EVDD	**1**	CBD	23,285	55,883
		Northern	33,538	80,492
		Southern	16,400	39,361
	7	CBD	6,025	14,461
		Southern	9,030	21,671
	23e	CBD	836	2,006
		Southern	1,025	2,460
	32x	CBD	760	1,823
		Southern	1,045	2,507
Total BVKT			**512,551**	**1,230,124**

The timetabled annual BKVT for all services on the listed routes is 4,417,178 km. This means that the DDD and EVDD vehicles currently make up 28% of the BKVT on the listed routes.

The values were checked against the total HVKT for each network and it was observed that the bus HVKT was less than the total HVKT for the network. This gave confidence that the traffic data in the RAMM database was realistic.

3.5.2 Passenger Occupancy Distribution

Analysis of the passenger data showed that the passenger occupancy distribution was significantly different to that assumed during the earlier studies. This was updated in the model for each route per the actual occupancy distribution.

The data provided only showed the occupancy per each "tag on/off" of the bus-card user and do not include the cash passengers. Therefore, there are trips where the occupancy of the vehicle is <0. It was assumed that the proportion of cash passengers was low and do not have a significant impact on the overall loading distribution of the buses.

It was also noted that the maximum occupancy of both the DDD (101 passengers) and EVDD (82 passengers) vehicles were exceeded on all routes – majority of which occurred in the CBD zone. Refer to Table 3-3. The distance travelled by both the DDD and EVDD vehicles when the GA limits are exceeded are also presented in this table. Note that the ratio of distances travelled by the DDD and EVDD vehicles above the GA limits is approximately 1 to 4.

Table 3-3 BVKT Operated Above GVM and GA Limits

Route	BVKT DDD (km)		BVKT EVDD (km)		
		Distance travelled above GVM limit (Occupancy ≥ 101)	**Distance travelled above GA limit (Occupancy ≥ 82)**	**Distance travelled above GVM limit (Occupancy ≥ 82)**	**Distance travelled above GA limit (Occupancy ≥ 42)**
1	350	2729	638	23164	
7	38	375	20	879	
23e	6	83	0	34	
32x	257	1241	6	680	
3	142	567			
31x	10	127			
36	60	232			
56	0	42			
57	80	473			
58	57	204			
Total		**1001**	**6072**	**664**	**24757**
	0.1% of total DDD distance	0.6% of total DDD distance	0.3% of total EVDD distance	11.2% of total EVDD distance	

The actual recorded passenger occupancy is significantly different to that assumed in the original analysis. The recorded passenger information shows that the DDD and EVDD were loaded greater than 80% occupancy for less than 1% of the total distance travelled across both the CBD and Northern and Southern zones. Compared to the original assumption that 45% of all peak services in the CBD and 11% in the Northern and Southern areas would be loaded to 80% capacity or above.

This calculation uses the assumed distribution of total weight between the front and rear axles and the idealised passenger loading numbers and weights. The reality of human nature and variability means that the reported numbers may be at odds with the study assumptions.

The graphs below illustrate the bus kilometres travelled by month where the rear axle exceeded the GA limits. For the DDDs the difference between GA and the HCUB weights is 19 passengers (23%). For the EVDDs the difference is 38 (90%). These graphs show that the average distance does not exceed the HCUB limits. The EVDDs travel further distance above the GA limits compared to the DDDs.

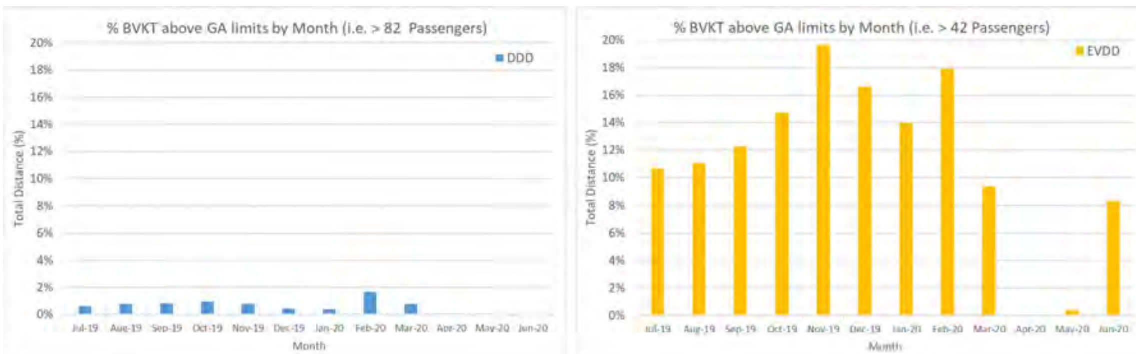

Figure 1: Total monthly distance travelled above the GA limits

3.5.3 Axle/load configurations and proposed BVKT

The estimated loading in the 2019 study used the passenger data provided by GWRC for the bus operations between 01 March 2019 and 31 July 2019. The total BVKT over this period was prorated up to 12 months based on the information provided i.e. all bus trips were considered in the analysis and not just peak hour trips as in the 2017 study. The total BVKT used in the analysis is summarised in Table 3-2.

For the 2020 study GWRC provided updated passenger data for EVDD buses with 42 or more passengers, and DDD buses for 82 or more passengers for the period June 2019 to July 2020. This data was then used (along with the 2019 annual BVKT data) to determine the percentage of BVKT where the buses were 80% loaded, 90% loaded, etc.

It has been assumed that the three-axle Large Vehicle buses (LV) buses are already operating on the routes with axle masses under the GA limits and that the pavement wear caused by these LV buses is already covered by the current pavement maintenance costs.

An assessment of the tare weights and front/rear load distributions were made to enable the relative pavement wear calculations to be performed. The assumed load distributions are based on information received from GWRC and are shown in Table 3-4. Due to the way the pavement wear model is configured, the design vehicles are assumed to operate at their maximum masses over the entire network, this approach produces an upper bound cost which provides some allowance for unquantified events/costs.

The split in loading between the front and rear axles was calculated to attempt so that both axles were loaded to a similar percentage for the respective axle limits.

The bus HVKT (BVKT) value for each route was determined from the GWRC passenger data for the bus operations between 01 March 2019 and 31 July 2019. The total BVKT over this period was prorated up to 12 months.

The vehicle efficiency gained from using the higher capacity DD buses was calculated on the basis that additional LV trips would be required to transport the number of passengers that would be carried on the network by DD buses at the proposed frequencies.

GWRC has provided a report that gives the passenger loading when the axle masses are equal to the GA limits and actual passenger loading density for the CBD and urban zones.

This information was used to calculate a weighted cost based on the percentage of time in different loading ranges (10% bands) for when the bus was operating with axle masses above the GA limits. To do this, the calculated cost for a bus operating at a specified passenger loading was multiplied by the percentage of time at that level of passenger loading to arrive at the weighted cost for that passenger loading. The individual weighted costs were then added together to give a total weighted cost for the route.

Table 3-4 Bus Loading Summary

		Front (Single Axle/Single Tyre)	Rear (Double Axle/Dual + Single Tyre)	Rear (Single Axle/Dual Tyre)	Total
DDD	Tare (t)	4.24	10.69	-	14.93
	Passenger No			-	101
	Passenger Mass (t)	2.035	6.045	-	8.08
	Total Mass (t)	6.275	16.733	-	23.01
	ESA (4th Power)	1.69	4.15	-	5.84
	Reference Load (t)	5.5	11.7	-	
EVDD	Tare (t)	4.24	-	7.886	12.13
	Passenger No		-		82
	Passenger Mass (t)	1.989	-	4.571	6.56
	Total Mass (t)	6.229	-	12.457	18.69
	ESA (4th Power)	1.64	-	5.33	6.97
	Reference Load (t)	5.5	-	8.2	

3.5.4 Number of buses

The 2017 study used GWRC data on the anticipated EVDD and DDD bus numbers for each bus operator and routes in year 1. This included the percentage of the year that the buses were in service as some DDDs were not programmed to enter service until either October 2018 or January 2019.

The output of the cost model was altered to provide a cost per route assuming 1 bus trip per route per weekday (250 trips per year). This change allowed us to calculate the cost for a specified number of buses rather than assuming that all peak period buses were operating in the HPMV range.

3.5.5 Bus Stops

The annual cost of reconstructing bus stops remains unchanged from the 2019 study and has been estimated at $750,000 per year. An amount has been allocated to the DDD/EVDD costs by the following methodology:

a) The annual pavement wear cost is calculated where the DDD/EVDDs are replaced by LVs during the peak period ($9,732);

b) This cost is converted into a percentage of the annual maintenance cost on the bus routes11,6M. This calculated percentage is then multiplied by the estimated bus stop costs (0.08% x $750,000 = $606);

c) The DDD/EVDD have, on average, an ESA multiplier of 12 compared to an LV. The bus stop cost calculated above is factored by the multiplier to give an additional annual cost of ($606 x 12 = $7,272).

4. Route costs

The results from the analysis are summarised in Table 4-1.

The total expected additional cost per annum from an increase in bus axle weights for all routes is $124.9k which is an increase of 1.1% on the total bus route expenditure of $11.6M.

The annual additional spend on bus stop maintenance was calculated at $750k, assuming a high-volume route would last five years and the lower volumes were prorated up. It is expected that the 12t single-axle dual-tyre rear axle of the EVDD will cause significant damage to the stops for both surfacing and structural. This additional cost is not included in the results for the individual bus routes.

Table 4-1 Summary of costs per route per year

Diesel Double Decker Buses (DDD)			Electric Vehicle Double Decker Buses (EVDD		
Route	**No. Trips/day**	**Cost**	**Route**	**No. Trips/day**	**Cost**
1	12	$ 10,141	1	24	$ 82,933
7	11	$ 515	7	16	$ 1,038
23e	9	$ 287	23e	6	$ 91
32x	13	$ 10,174	32x	6	$ 8,312
3	17	$ 1,508	-	-	-
31x	6	$ 427	-	-	-
36	6	$ 644	-	-	-
56	2	$ 76	-	-	-
57	4	$ 1,051	-	-	-
58	1	$ 403	-	-	-
Annual Pavement Cost		$ 25,224			$ 92,374
Bus stop cost		$ 2,131			$ 5,141
Total		**$ 27,355**			**$ 97,515**
Total Cost		**$ 124,870**			

Note that the ratio of pavement wear costs between the DDD and EVDD vehicles is approximately 1 to 4 which is comparable to the distances travelled above the GA limits calculated in Table 3-3.

In addition to the calculation of the additional wear cost as detailed above, the pavement wear cost that would be attributed to the bus traffic on a route if the bus was operating under GA limits was calculated. This was done to provide a relativity check on the additional estimated costs for the HCUBs. These base costs for the nominated routes are given in Table 4-2 and show that the estimated pavement wear costs that would be incurred if the routes were serviced by regular single deck buses (LVs) is $1,296k per year for all the trips on the routes and that the addition of a limited number of HCUBs results in additional $125k per year, an additional 10% on the nominated routes.

Table 4-2 Summary of costs per route per year for GA buses

Route	Cost
1	$750,072
3	$235,097
7	$149,043
36	$13,812
56	$20,951
57	$20,276
58	$21,221
23e	$38,872
31x	$44,394
32x	$2,165
Annual Pavement Cost for GA buses	**$1,295,902**

5. Conclusion

The additional pavement wear-related costs that could be attributed to an increase in the axle mass for the high-capacity urban buses (DDD and EVDD) on the WCC road network was determined using historic pavement and surfacing maintenance cost for the past 5 years (2016 – 2020) on the network, and selected bus axle and load configurations based on actual passenger data for the period July 2019 to June 2020.

The cost of additional pavement wear due to the new DDD and EVDD buses is defined as the cost of pavement wear that occurs when a vehicle is estimated to be operating with axle masses that are greater than the allowable axle masses for General Access (GA) as defined in the VDAM Rule.

It is expected that more of these high-capacity urban buses will be introduced to the bus fleet over a period of time dictated by demand. Such demand may also result in certain routes carrying increased number of passengers which will affect the loading and pavement wear costs. This provides the opportunity to update the report in following years with updated passenger numbers and maintenance costs.

Estimated cost

The maintenance cost on the bus routes for the 2016 – 2020 period is higher than for the 2012 – 2016 period. From the data it appears as if the quality of record keeping of maintenance cost items has improved significantly. The increase in maintenance costs may also be attributed to a real increase in maintenance on these routes.

The 2020 bus loading distributions were lower compared to the earlier studies. This is likely due to the analysis period (July 2019 – June 2020) coinciding with the COVID-19 lockdown period which included an approximately 7-week lockdown period between March and May 2020.

The combination of these effects is shown in the estimated additional pavement maintenance costs per year as a result of operating Diesel Double Decker buses (DDD) and Electric Double Decker buses (EVDD) above the GA mass limits are:

DDD	$27,355
EVDD	$97,515
Total Additional Cost	**$124,870**

The ratio of pavement wear costs between the DDD and EVDD vehicles is approximately 1 to 4 which is comparable to the distances travelled above the GA limits by each of these vehicles.

The additional cost calculated for the 2020 update lies between the 2017 and 2019 estimates of $166,750 and $58,645 respectively. The expected increase is approximately 1.1% of the annual maintenance cost for the bus routes and the impact is lower than what other stakeholders may expect. The 2020 results are considered more reliable as it is based on actual passenger data for the period under consideration and updated pavement maintenance costs.