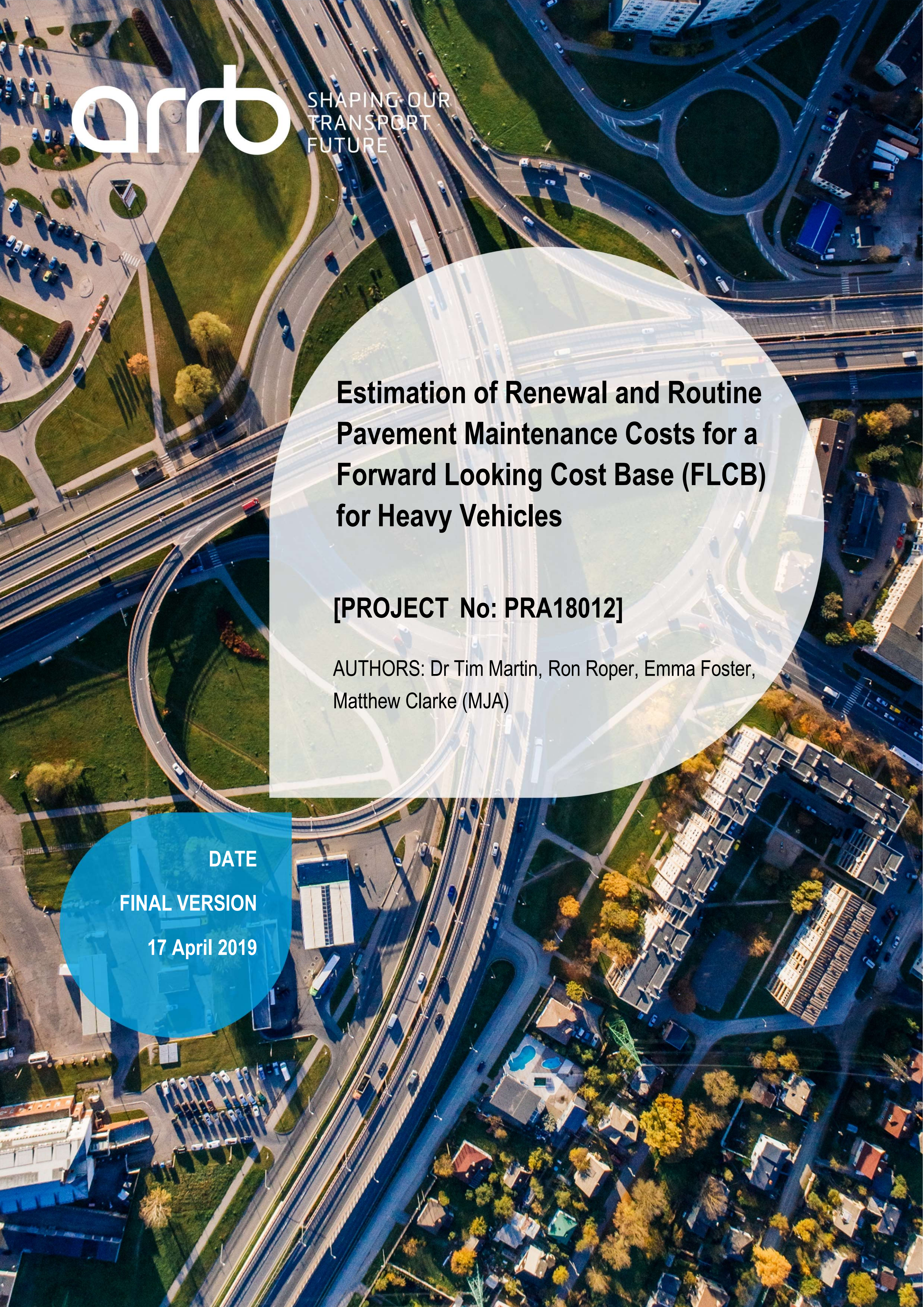

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Estimation of Renewal and Routine Pavement Maintenance Costs for a Forward Looking Cost Base (FLCB) for Heavy Vehicles

[PROJECT No: PRA18012]

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DATE

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SUMMARY

This report documents the ARRB estimates of the following expenditures for the first four years of the forward looking cost base (FLCB) for heavy vehicles within the Victorian arterial road network:

- The annual routine maintenance, including both off pavement and pavement-related expenditures, that form part of the operating expenditure component of the annual revenue requirement (ARR) produced by the FLCB model.
- The periodic maintenance and rehabilitation expenditures of pavements that contribute to the capital expenditure (CAPEX) component of the ARR. No significant expenditure on additional lanes for increased traffic capacity was found to be necessary for the first four years of the FLCB, apart from what may have been allowed in the forward CAPEX estimates provided by Transport for Victoria.

The impact of low (1%) and high (3%) traffic growth scenarios on the annual operating expenditure and CAPEX was estimated and was found not to be significant for the first four years of the FLCB.

The estimates of annual operating and renewal (CAPEX) expenditures were based on a highly granulated model of the Victorian arterial road network in 2018/19 using a detailed pavement life-cycle costing (PLCC) analysis over a 30-year period with a medium (2%) annual traffic growth rate, referred to as the dTIMS (Deightons Total Infrastructure Management System) analysis. This was ultimately chosen as the basis for the FLCB. An ARRB PLCC analysis, based on a less granulated model of the Victorian arterial road network, was also undertaken and was used to examine the impact of the low and high traffic growth scenarios on the annual operating and CAPEX expenditures.

All the expenditures from both of the above PLCC analyses were under unconstrained budgetary conditions. The annual CAPEX and operating expenditures for the Victorian arterial road network over the 30-year analysis period were also estimated.

Further discussion regarding the basis of the ARRB estimates is outlined below.

NETWORK DATA LIMITATIONS

Several of the road use variables for both cost allocation and the PLCC analyses were based on average estimates of heavy vehicle characteristics across the arterial road network. Due to some changes in the road use variables and network road length, there were changes made to the previous 2017 ARRB cost allocation matrix.

PAVEMENT AGE

This variable was estimated from the roughness measurements taken along each of the six road types. This is a current deficiency of the VicRoads database because the AGE variable significantly influences pavement performance and consequently the expenditure estimates from the PLCC analyses.

PAVEMENT STRENGTH SNC_0

The estimates of the initial pavement strength, SNC_0, were based on the strength value needed to carry the estimated design traffic load/lane which in turn were based on assessment of the current traffic loads. This is also a current deficiency of the VicRoads database because the SNC_0 variable also influences the expenditure estimates from the PLCC analyses.

BASIS FOR ESTIMATING RENEWAL CAPEX EXPENDITURE FOR THE FOUR YEAR FLCB

The 2018/19 dTIMS PLCC 30-year analysis of the Victorian arterial road network was considered to be the most appropriate basis for estimating the first four years CAPEX and operating expenditures for the FLCB.

The 2018/19 dTIMS analysis software is also used by some Australasian road agencies for their pavement management systems (PMS). Consequently, it has credibility with many of the stakeholders.

TREATMENT OF RENEWAL CAPEX FOR THE FIRST YEAR OF THE FLCB

The dTIMS model identifies a significant maintenance gap in the VicRoads network, requiring a large CAPEX renewal expenditure to be undertaken to bring the road network up to the specified service level standard. The large CAPEX renewal expenditure for the first year of the four-year FLCB, as estimated by the budget unconstrained 2018/19 dTIMS analysis, is well beyond the capacity of industry to undertake in a single year. It is assumed that this expenditure is spread over the first five years of the analysis.

COST ALLOCATION MATRIX

As noted, some of the relatively minor changes to road use and used in this study also resulted in some changes to the cost allocation matrix.

ACKNOWLEDGEMENTS

The support from Norbert Michel, formerly of ARRB, for his initial oversight of the dTIMS analysis in this study.

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1 INTRODUCTION

The Australian Road Research Board (ARRB), in partnership with Marsden Jacob Associates (MJA), were engaged by the Victorian Department of Treasury and Finance (DTF) to develop a forward looking cost base (FLCB) for appropriately charging heavy vehicles for their use of the Victorian arterial road network. Cost-reflective heavy vehicle user charges will allow sustainable long-term funding for the Victorian arterial road network. The following deliverables were required by the DTF:

- the methodology and estimates for the four-year FLCB being the sum of the regulatory asset base (RAB) and the annual revenue requirements (ARR)
- the cost allocation of the FLCB expenditures to the six different road types in accordance with the 2017 ARRB cost allocation cost matrix
- estimation of mass-distance heavy vehicle charges for each road type.

The FLCB expenditure estimates should be based on sustainably funding the costs of the road network attributable to heavy vehicle use by using heavy vehicle charges.

This report documents the ARRB estimates of the following:

- The annual routine maintenance, including both off pavement and pavement-related expenditures, that form part of the operating expenditure component of the annual revenue requirement (ARR) produced by the FLCB model.
- The periodic maintenance and rehabilitation expenditures of pavements that contribute to the capital expenditure (CAPEX) component of the ARR. No significant expenditure on additional lanes for increased traffic capacity was found to be necessary for the first four years of the FLCB, apart from what may have been allowed in the forward CAPEX estimates provided by Transport for Victoria.
- The impact of both low (1%) and high (3%) annual traffic growth scenarios on the operating expenditures and CAPEX.

The operating expenditures and CAPEX are required for the first four years of the FLCB based on a pavement life-cycle costing (PLCC) analysis of the Victorian arterial road network over a 30-year analysis period using a medium (2%) annual traffic growth rate.

2 METHODOLOGY

This section details the approach used to model the Victorian arterial road network as six discrete arterial road types (see Appendix A) and derive the road use and climate variables used in the subsequent PLCC analyses outcomes (see Section 3) and cost allocation processes detailed in Appendix B.

2.1 ASSEMBLY OF ARTERIAL ROAD NETWORK AND ROAD USE DATA

The VicRoads arterial road network and road use data were sourced from ARRB's internal database. Table A 1 in Appendix A summarises road length, lane length and road use for each of the six arterial road types comprising the VicRoads arterial road network. Column 2 in Table A 1 shows the road lengths used in part of the earlier study for the DTF (Martin 2017b). Column 5 in Table A 1 shows the updated road lengths used in this study. These updated road lengths were used in the earlier 2017 and the current 2018–19 estimation of the pavement renewal expenditures, which allows comparison of the earlier and current estimations of pavement renewal expenditures.

Table A 1 shows the lane-km for the two main types of flexible pavements in the Victorian road network being: (i) unbound granular material (GN) which is mainly present in the rural areas; and, (ii) asphaltic concrete material (AC) which is mainly present in the urban areas. These different pavement materials need to be identified because they have different construction and maintenance costs and approaches to their design which also influence cost allocation to heavy vehicles.

In Table A 1 and Table A 2, for cost allocation purposes, each of the six arterial road types had an estimate of a whole carriageway annual average daily traffic (AADT) and percentage commercial vehicles (%CV) based on a road length weighted average AADT and %CV respectively for each of the road links making up each road type.

2.1.1 DETAILED ESTIMATES OF ROAD USE

ESTIMATION OF ESA/HV

The value of the heavy vehicle traffic loading, ESA/HV, for each arterial road type in Table A 2 was estimated by the number of axle groups per heavy vehicle axle group, NHVAG, multiplied by the number of ESAs per heavy vehicle axle group, ESA/HVAG. These values were based on those in Table D1 of Austroads (2012) that represent the heavy vehicle traffic at specific weigh-in-motion (WIM) sites in the arterial road categories across Victoria.

ESTIMATION OF ESA/LV

The ESA per light vehicle, ESA/LV, was based on a median gross light vehicle weight (GVW/LV) of 1.6 tonnes which, when loaded over two single axles, gives an estimated ESA/LV value as follows in Equation 1:

$$\begin{aligned} ESA/LV &= 2 \times [(1.6 \times 0.5)/5.4)]^4 \\ &= 0.000974 \end{aligned} \quad (1)$$

where the numerator of the expression in the bracket is half of the GVW/LV, and the denominator is the reference axle load for a single axle with single tyres estimated in accordance with Austroads (2012) and the application of the fourth power law.

ESTIMATION OF GVM/HV

The gross vehicle mass per heavy vehicle, GVM/HV, for each arterial road type in Table A 2 was estimated by independently assessing the ESAs per axle group for a given load on each axle group for typical HV configurations (rigid trucks, articulated combination vehicles, etc.) under fully laden conditions. Both the ESAs and GVMs were summed for each HV configuration and plotted against each other to form a simple linear relationship as shown in Figure 2.1.

The resulting relationship has a reasonable goodness of fit (r^2) of 0.8 for the fully laden condition. The relationship for the partially-laden condition has a much lower goodness of fit (r^2) of 0.31 as shown in Figure 2.2. It was decided to use the Figure 2.1 relationship because of its superior fit to the data even though heavy vehicles are not always fully laden. This relationship is as follows in Equation 2:

$$GVM/HV = (ESA/HV)/0.1215 \qquad (2)$$

Figure 2.1: ESAs versus GVMs for fully laden heavy vehicle configurations

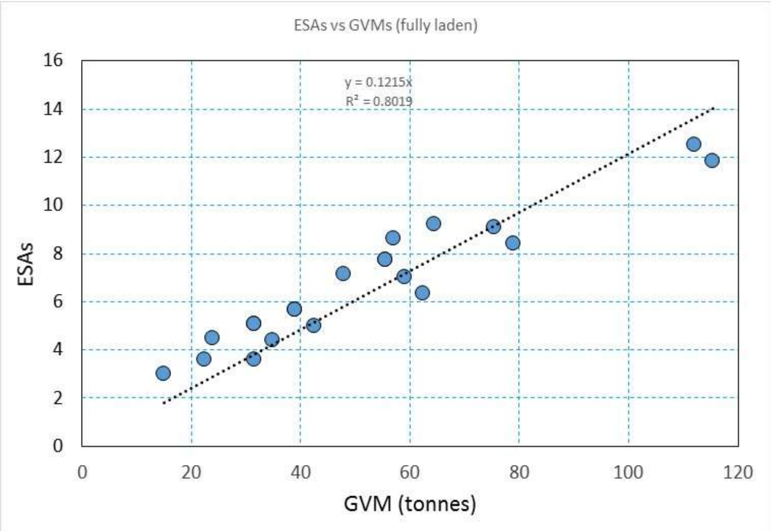
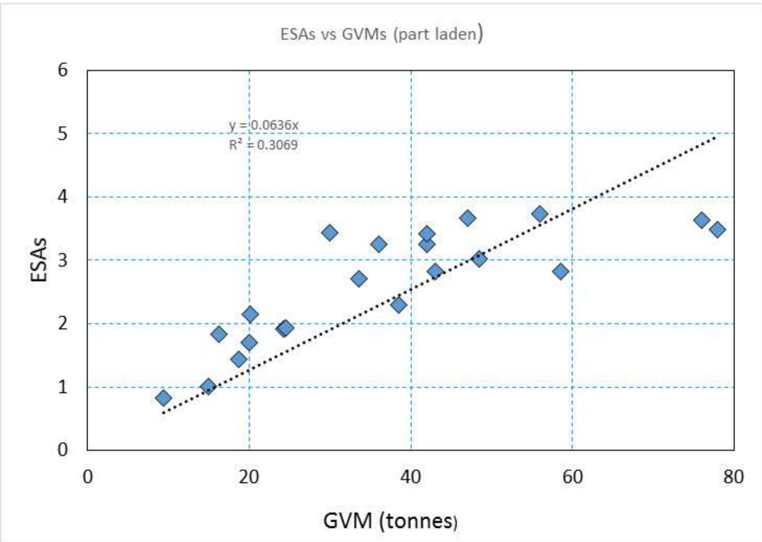


Figure 2.2: ESAs versus GVMs for partially laden heavy vehicle configurations



ESTIMATION OF GVM/LV

For the purposes of this study, the median gross vehicle weight per light vehicle, GVW/LV, was taken as 1.6 tonnes for all road types, as used above.

ESTIMATION OF PCU/HV

Jamal (2017) reported that passenger car units, PCUs, range from 1.0 for passenger cars and up to 3.0 (or 4 in some cases) for heavy vehicles. It can be seen from Table A 2 that the PCU/HV values vary from 2.0 to 2.8 as the GVM/HV values increase from 9.7 to 22.9 tonnes. From inspection this appears to be a reasonable estimate.

ESTIMATION OF PCU/LV

A constant PCU value per light vehicle, PCU/LV, of 1.4 was adopted for all road types.

ESTIMATION OF MESA/LANE/YEAR

For the purposes of estimating the load-related road wear costs (maintenance and rehabilitation), the annual traffic loading on each road type was calculated as follows in Equation 3 :

$$MESA/lane/year = (\%CV/100 \times AADT/carriageway \times 0.5 \times LDF \times ESA/HV \times 365)/10^6 \quad (3)$$

where

LDF = lane distribution factor for heavy vehicle traffic

= 0.65 for 3 lanes/carriageway (urban); 0.95 for 2 lanes/carriageway or less (rural) Austroads (2017)

all other terms are as previously defined

ESTIMATION OF DESIGN TRAFFIC LOADING/LANE

For the purposes of estimating the load-related pavement construction costs (new, replacement and extra lane pavements), the design traffic loading on each road type was calculated as follows in Equation 4:

$$MESA/lane = (\%CV/100 \times AADT/carriageway \times 0.5 \times LDF \times ESA/HV \times 365 \times DL)/10^6 \quad (4)$$

where

DL = design life (40 years) for freeways and major arterial pavements plus allowance for 2.0% annual traffic growth factor = 60.4 years

= design life (30 years) for other pavements plus allowance for 2.0% annual traffic growth factor = 40.6 years

all other terms are as previously defined

PAVEMENT AGE

Pavement age, AGE, is a pavement characteristic needed if the load-related pavement wear is to be estimated (see Equation 7). This pavement characteristic was not able to be supplied by VicRoads. However, it was inferred from the general condition of the pavement – reported as road roughness, a measure of ride quality of a road. A relationship between road roughness, R(t), (measured in terms of NAASRA counts, NRM) and pavement AGE (years) was developed from an AGE-based roughness deterioration model (Martin 1996a). The form of the model is as follows in Equation 5:

$$R(t) = R(t)_0 + A \times AGE^2 + B \times AGE \quad (5)$$

where

$R(t)_0$ = Roughness at zero age (immediately post construction)

= 31 NRM (urban and rural freeways and major arterials)

= 40 NRM (urban and rural other arterials)

A = 0.01195 (urban and rural freeways and major arterials)

= 0.00676 (urban and rural other arterials)

B = 2.836 (urban and rural freeways and major arterials)

= 1.296 (urban and rural other arterials)

Equation 5 was solved iteratively for AGE for each road category based on the carriageway/lane-kilometre length weighted average of the measured roughness on each road category (see Table A 2).

PAVEMENT STRENGTH (SNC_0)

The initial pavement subgrade strength, SNC_0, is currently not measured by VicRoads at a network level by the usual surface deflection method. However, it can be inferred from an estimation of the design traffic load based on the assumption that roads are designed to adequately carry their design traffic load. The initial pavement subgrade strength, SNC_0, is related to the design traffic load, MESA/lane as follows in Equation 6 (Martin 2017b):

$$SNC_0 = 1.128 \times (MESA/lane \times 10^6)^{0.1033} \quad (6)$$

where

MESA/lane = design traffic loading (see Equation 4).

The SNC_0 values of pavement strength were estimated for each arterial road type (see Table A 1).

On each road type, road segments were modelled as ‘weak’, ‘moderate’ and ‘strong’ based on SNC_0 calibration factors of 0.75, 1 and 1.25 respectively. Overall, some 80% of the road segments were modelled as ‘moderate’, 10% were modelled as ‘weak’ and 10% were modelled as ‘strong’. This allowed for the natural random variation of pavement strength in the network.

THORNTHWAITE MOISTURE INDEX (TMI)

The Thornthwaite Moisture Index (TMI) value (Thornthwaite 1948) for each of the VicRoads regional roads in each category was estimated based on its GPS co-ordinates (Austroads 2010). The results are shown in Table A 2. A road length-weighted average TMI was estimated for each road type. It can be seen from Table A 2 that there is a wide range of TMI values from each of the Regions on many of the road types.

2.2 DETERMINATION OF COST ALLOCATION MATRIX

The cost allocation matrix developed in 2017 (Martin 2017b) depends to a large extent on the road use parameters that apply to each of the six road types as shown in Table A 2. The following sections use the road use measures determined in Section 2.1.1 to update the cost allocation matrix (see Table B 1, Appendix B).

2.2.1 LOAD RELATED ROAD WEAR COSTS

The functional distress models developed by Martin and Choummanivong (2010) from observational and experimental data allow separate estimation of the load-related portion of road wear (Martin 2011). Overall road wear is well-represented by road roughness. Based on the roughness deterioration model (Martin & Choummanivong 2010), the percentage (%) load-related wear, IRI_l, can be determined using the following algorithm (Equation 7) for sealed flexible unbound granular pavements:

$$IRI_l = 70.533 \times (1 - EXP(-17.714 \times m \times AGE)) - 3.46 \times SNC_0 + 27.131 \times MESA \quad (7)$$

where

m = environmental coefficient (Paterson 1987)

= $0.0197 + 0.000155 \times TMI$ (Martin 1996b)

TMI = Thornthwaite Moisture Index

AGE = number of years since pavement was constructed/replaced or rehabilitated, whichever is the lesser

SNC_0 = pavement/subgrade strength value as designed and initially constructed (AGE = 0)

$MESA$ = millions of ESAs, or SARs, of traffic loading per lane per year

The independent variables estimated for each road type (see Table 2.1and Table 2.2) were substituted into Equation 7 to calculate the % load-related road wear costs for each road type. These estimates are summarised in Table A 2. The non-load-related, or common costs, are simply estimated as follows in Equation 8:

$$\%\ \text{common costs} = 100 - \%\ \text{load-related road costs} \quad (8)$$

2.2.2 LOAD-RELATED PAVEMENT CONSTRUCTION COSTS

GRANULAR PAVEMENTS

The minimum pavement thickness for the base pavement cost is the thickness needed for no usage by heavy vehicles with the pavement thickness being sufficient to carry construction and maintenance traffic. Figure 8.4 of Austroads (2012) provides a minimum granular pavement thickness (ranges from 100 to 200 mm) for a design traffic load range of 10^5 to 10^8 ESAs/lane. The median thickness of 150 mm can be regarded as the acceptable minimum thickness, t_{min}, for light vehicles only.

In addition, a total pavement thickness, *t*, is required for a pavement base for design CBR values of 3, 5 and 7 respectively to support the design traffic load. Taking a typical CBR value of 5 to estimate the total thickness, *t*, the % load-related cost portion for a pavement is the portion of the total pavement thickness, *t*, that exceeds the minimum pavement thickness as shown in Equation 9 (Martin 2017a):

$$\% \text{ load-related cost} = ((t - t_{min})/ t) \times 100 \qquad 9$$

Using the design traffic values in Table 2.1, the required granular pavement thickness, *t*, is estimated from Figure 8.4 of Austroads (2012) for the granular based rural freeways and arterials. The values of *t* extracted from Figure 8.4 for the design traffic values for rural arterials (see Table A 2) are shown in Table 2.1.

Table 2.1: Estimated granular pavement thickness for rural roads

Arterial road types	Design traffic load (MESA/lane)	t_{min} (mm)	t (mm)
Fwy rural	28.3	150	500
Major hwy rural	5.4	150	460
Other hwy rural	1.0	150	410

The estimated % load-related granular pavement construction costs are summarised in Table B 1. The non-load-related, or common costs, are simply estimated as follows in Equation 10:

$$\% \text{ common costs} = 100 - \% \text{ load-related pavement construction costs} \qquad 10$$

ASPHALT PAVEMENTS

Design charts are provided in Austroads (2012) for subgrade conditions corresponding to CBR values of 3, 5 and 7. These give the thickness of the asphalt layer as a function of the thickness of the granular subbase and the design traffic load. For the purpose of estimating % load-related pavement costs, the thickness of the granular subbase was assumed to remain the same as for the minimum pavement, with the thickness of the asphalt layer changing in response to the design traffic load.

The % load-related pavement cost is calculated using the following relationship in Equation 11(Martin 2017a):

$$\% \text{ load-related cost} = 100 - \frac{(t_{g\,\min} + CF \times t_{a\,\min})}{(t_g + CF \times t_a)} \times 100 \qquad 11$$

where $t_{g\,min}$ is the minimum thickness of the granular subbase (assumed to be 100 mm), t_g is the thickness of the granular material, $t_{a\,min}$ is the minimum thickness of asphalt (assumed to be 40 mm) and t_a is the asphalt thickness required for the design traffic load. CF is the cost of asphalt per unit of volume divided by the cost of granular material per unit of volume (assumed to be 3.5).

Table 2.2 shows the values of $t_{g\,min}$, t_g, $t_{a\,min}$ and t_a extracted from Figure ECO1 (Austroads 2012) for their respective urban arterial road type design traffic values (see Table A 2).

Table 2.2: Estimated asphalt and granular pavement thickness for urban roads

Arterial road types	Design traffic load (MESA/lane)	$t_{g\ min}$ (mm)	t_g (mm)	$t_{a\ min}$ (mm)	t_a (mm)
Fwy urban	72.0	100	200	40	320
Major hwy urban	18.0	100	200	40	240
Other hwy urban	6.4	100	200	40	225

The estimated % load-related asphalt pavement construction cost are summarised in the updated cost allocation matrix in Table B 1. The non-load-related, or common costs, are estimated by Equation 10.

2.3 ARTERIAL ROAD NETWORK ANALYSIS

The basis for the ARRB estimates of the first four years for the pavement renewal expenditures (periodic maintenance and rehabilitation) for the ARR component of the FLCB was the use of a 30-year pavement life-cycle costing (PLCC) analysis of the Victorian arterial road network. Details of the road network road and lane lengths, climate, pavement types and traffic use are shown in Table A 1. The base case PLCC analysis was conducted using a 5% real discount rate, as used previously for an earlier study for DTF (Martin 2017a), with a traffic growth rate of 2%.

All PLCC analyses estimated the road agency costs (RAC) associated with maintaining the road network with surface maintenance and rehabilitation treatments that have unit cost rates that vary with treatment type and the location of the VicRoads Region (see Table 2.3). Road conditions, in terms of cracking, roughness, rutting and texture were maintained to set service levels (see Table 2.4) which were significant factors in estimating the RAC. Table 2.4 is a simplification of the VicRoads approach to setting service levels which vary with posted speed (speed limit) and road type. Most of these road conditions are used in a multi-criteria approach to initiating maintenance treatments which use indices that are a combination of the measured road conditions. The levels of service tend to decrease with decreased traffic levels. There were other conditions that also initiated maintenance treatments such as loss of surface aggregate and pothole patching; these works are usually classified as routine maintenance.

Table 2.3: Road agency maintenance treatment rates ($/m²)

Treatment type	VicRoads region					
Retexture_SS[(1)]	7	7	7	7	7	7
Retexture_AC[(2)]	7	7	7	7	7	7
Resurface_SS[(3)]	8.5	12.56	11.04	8.8	12.56	10.66
Resurface_AC[(4)]	61.58	33.52	29.44	59.84	33.52	41.2
Regulate_SS[(5)]	65	50	50	50	50	50
Regulate_AC[(6)]	65	65	65	70	65	50
Rehabilitation_SS[(7)]	70	114	105	56	114	75
Rehabilitation_AC[(8)]	150	150	150	150	150	150

1 *Retexture sprayed seal surface.*
2 *Retexture asphalt surface.*
3 *Resurface sprayed seal surface.*
4 *Resurface asphalt surface.*
5 *Regulate sprayed seal surface.*
6 *Regulate asphalt surface.*
7 *Rehabilitate sprayed seal pavement.*
8 *Rehabilitate asphalt pavement.*

Table 2.4: Arterial road levels of service for all road types

Road type	RMC class	Treatment type	Surface cracking (%)		Roughness (IRI)		Rutting (mm)		Texture loss
Freeway/highway (urban)	RMC1	Regulate AC			> 2.88	3.45	> 10	12	
		Rehab AC	> 20			3.45	> 10		
		Resurface AC	> 10			2.88		14	> 5
		Retexture AC				2.88		10	> 3
Major road (urban)	RMC2	Regulate AC			> 3.07	3.82	> 10	12	
		Rehab AC	> 20		> 3.82		> 10		
		Resurface AC	> 10		> 3.07		> 10		> 5
		Retexture AC			> 3.07		> 10		> 3
Other road (urban)	RMC2 – RMC3	Regulate AC			3.08–4.2		> 12	15	
		Rehab AC	20–30		3.82–5.33		12–15		
		Resurface AC	20–30		3.07–4.2		10–12		> 5
		Retexture AC			3.07–4.2		10–12		> 3
		Regulate SS			> 3.07	3.82	> 10	12	
		Rehab SS	20–30		3.07–4.2			12–15	
		Resurface SS	10–20		3.07–4.2			14	> 5
		Retexture SS							> 3
Ma	RMC2 – RMC3	Regulate AC			3.07–4.2		> 10	12–15	
		Rehab AC	20–30		3.82–5.33			12–15	
		Resurface AC	20–30		3.07–4.2			10–12	> 5
		Retexture AC			3.07–4.2			10–12	> 3
Major road (rural)	RMC3 – RMC_41	Regulate SS			3.07–4.2		> 12	15	
		Rehab SS	30		5.33			12–15	
		Resurface SS	20		4.2		> 12		> 5
		Retexture SS			4.2		> 12		> 3
Other road (rural)	RCM_41 – RMC_42	Regulate SS			3.45–4.2	4.2–5.33	> 12	15	
		Rehab SS	30		5.33		> 15		
		Resurface SS	20		4.2		> 12		> 5
		Retexture SS			4.2		> 12		> 3

2.3.1 DEIGHTON TOTAL INFRASTRUCTURE MANAGEMENT SYSTEM (DTIMS) PLCC ANALYSIS

Deighton Associates (2014) Total Infrastructure Management System (dTIMS) software was used for the PLCC analysis of the Victorian arterial road network, and was ultimately used as the source of the FLCB estimates. dTIMS was the same software used for the earlier DTF study of the impact on road conditions of reducing the road agency budget (Martin 2017a). In the Martin (2017a) study, the 24 083 km Victorian arterial roads network was represented by 34 000 individual road segments of varying length, structural and functional condition and traffic. In this current study, the Victorian arterial road network was represented by some 104 000 individual road segments to improve the accuracy and reliability of the analysis by capturing the variations in road conditions, climate and traffic. This increased granularity of the representation of the network had a substantial impact on the time dTIMS took for completion of the analysis using the base case of 2% annual traffic growth. Each of the six VicRoads Regions underwent a separate PLCC analysis.

The dTIMS network PLCC analysis included an estimate of pavement related routine maintenance. The off pavement related routine maintenance (rubbish collection, grass cutting, lighting, road side amenities, etc.) expenditure was arbitrarily estimated as being 50% greater than the pavement related routine maintenance expenditure on the basis of past experience and practice.

2.3.2 ARRB PLCC ANALYSIS

A PLCC analysis estimate of the Victorian arterial road network for pavement renewal expenditures was conducted in parallel with the dTIMS base case using the simplified ARRB PLCC model (Linard, Martin & Thoresen 1996) with the arterial road network represented by 13 240 individual road segments to dramatically reduce the analysis time. The reduced granularity of the ARRB PLCC analysis reduces the accuracy and reliability of the maintenance (renewal) expenditure estimates over the life-cycle analysis period of 30 years.

The ARRB PLCC base case analysis allowed a comparison of the renewal expenditures estimated by the dTIMS base case analysis. The ARRB PLCC parallel analysis was used specifically to estimate the changes in the pavement renewal expenditures due to the low (1%) and high (3%) annual traffic growth estimates. These changes were then applied to the base case pavement renewal expenditures estimated by the dTIMS analysis.

2.3.3 PLCC ANALYSIS OUTCOMES

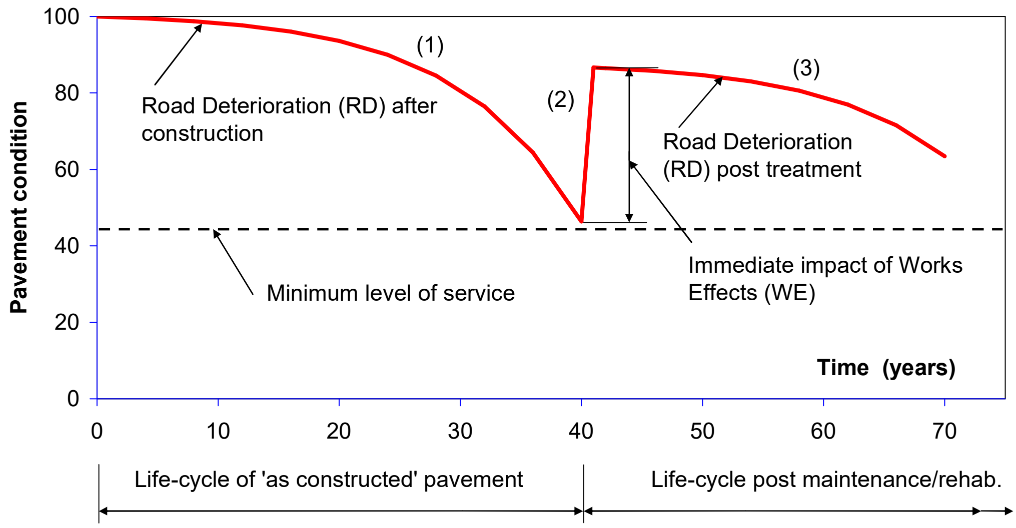
The RAC represent the pavement renewal (CAPEX) and the operating expenditures of routine maintenance. The road user costs (RUC) associated with the use of all vehicles on the network, and which involved travel speed (driver costs) and vehicle operating costs (fuel, tyres, oil, maintenance and repair costs, etc.), were also estimated as part of the PLCC analysis. The RUC model is based on a simplified World Bank's Highway Design and Maintenance Standard Road User Cost (HDM RUC) model by Thoresen and Roper (1996), which is similar to the amended ATAP PV2 uninterrupted flow model. The total transport costs (TTC) are the sum of the RAC and RUC, which aimed to be a minimum value under the set service levels and unconstrained budget through an optimisation process.

The use of an unconstrained budget 30-year PLCC analysis provides an upper bound (high) estimate of the CAPEX renewal and operating expenditures. This will also result in high early expenditures aimed at addressing current distresses that exceed the designated levels of service as shown in Table 2.4.

2.3.4 ARTERIAL ROAD PERFORMANCE CHARACTERISTICS

The life-cycle performance of the arterial road types post-construction has two phases: (i) road deterioration (RD); and, (ii) works effects (WE) as shown in Figure 2.3. Models for both the RD and WE phase were based on Australian observational and experimental data and are fully documented in Martin (2018). The RD models need some calibration to match the observed field performance, which is influenced by local factors of climate and drainage. Table 2.5 summarises the observed performance of each of the arterial road types and forms the basis of calibration of the RD models for each road type.

Figure 2.3: Use of RD and WE models in PLCC analysis



Note:
(1) Road deterioration (RD) phase after construction (gradual deterioration phase).
(2) Impact of works effects (WE) maintenance surface treatment such as rehabilitation.
(3) Road deterioration phase after impact of WE.

Table 2.5: Observed performance (roughness and rutting) for arterial roads

Arterial road types	Location	Rut/year (mm/year)	IRI/year (m/km/year)
Freeways	Urban	0.15	0.03
	Rural	0.12	0.03
Major arterials	Urban	0.32	0.06
	Rural	0.32	0.06
Other arterials	Urban	0.5	0.1
	Rural	0.5	0.1

3 ESTIMATES OF OPERATING AND CAPEX EXPENDITURES FOR FLCB

This section documents the outcomes of the PLCC analyses that were based on the variable inputs with the network model detailed in Section 2. The PLCC analyses determined the operating expenditures and CAPEX for the 30-year analysis period using the dTIMS PLCC model and ARRB PLCC model.

3.1 VICTORIAN ARTERIAL ROAD NETWORK LIFE-CYCLE EXPENDITURES

3.1.1 NETWORK LIFE-CYCLE COST OUTCOMES

Table 3.1 summarises the network 30-year analysis outcomes using both the dTIMS and ARRB PLCC analysis tools. The 2018–19 dTIMS analysis had over three times the number of road segments than the 2017 dTIMS analysis and also had the lowest estimated total cumulative RAC (total costs over 30-year life-cycle, undiscounted) with a slightly lower traffic growth rate of 2% than the 2.5% growth rate used in the 2017 dTIMS analysis. This outcome suggests that a more granulated model of the road network can be expected to more accurately reflect the network condition and performance. It is interesting to note that the present value (PV) of the RAC was only slightly higher for the 2018–19 dTIMS analysis with more segments, which may have been due the higher expenditure in the first year of the analysis dealing with the backlog of maintenance requirements that were more accurately represented by the increased number of segments. This is discussed further in Section 3.2.1.

Table C 1 in Appendix C details the full 30-year analysis outcomes of annual arterial road network expenditure estimated by the 2018–19 dTIMS analysis.

Table 3.1: Network pavement 30-year life-cycle costing analysis outcomes

Analysis type	RAC(1) total life-cycle costs (30-years undiscounted)	RAC(1) PV (5% real discount rate)
dTIMS 2017 run (Martin 2017a), 34 000 segments, 2.5% growth	$18 301 845 509	$8 637 118 473
dTIMS 2018–19 run, 104 000 segments, 2% growth	$14 534 724 120	$8 673 308 499
ARRB PLCC 2019 run, 13 240 segments, 2% growth	$18 172 854 000	$7 610 731 000
ARRB PLCC 2019 run, 13 240 segments, 1% growth	$16 842 608 000	$7 150 733 000
ARRB PLCC 2019 run, 13 240 segments, 3% growth	$18 757 783 000	$7 859 517 000

3 *These RAC estimates exclude off pavement routine maintenance.*

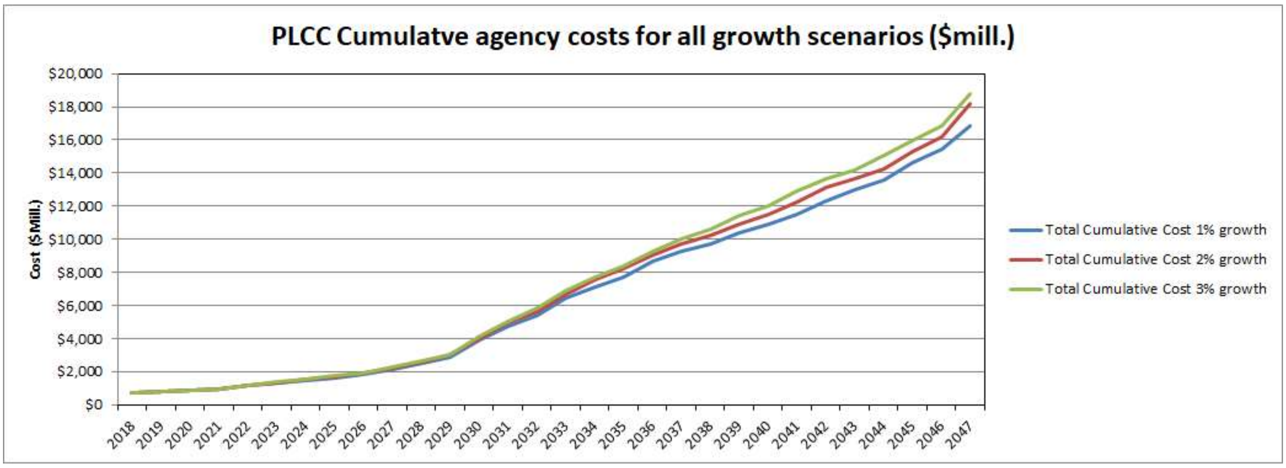
The ARRB PLCC analyses produced similar estimates of the total RAC to the 2017 dTIMS analysis, although the PV of the RAC from the ARRB PLCC analyses was lower than the 2017 dTIMS analysis. The 2017 dTIMS analysis used 34 000 road segments to represent the network, while the ARRB PLCC analyses used 13 240 road segments. This reduced PV of the 2017 dTIMS analysis could have been due to the coarser representation of the network. In the ARRB PLCC analyses with even fewer road segments, less maintenance expenditure occurred in the first year of the analysis, while major rehabilitation expenditures were deferred until later years in the analysis.

3.1.2 IMPACT OF TRAFFIC GROWTH

The ARRB PLCC analyses were sensitive to the traffic growth scenarios when comparing their total cumulative RAC over the 30-year analysis period. From the base case of 2% annual traffic growth, the 1% traffic growth scenario reduced the total RAC by 7.32% below the base case, while the 3% traffic growth scenario increased the total RAC by 3.22% above the base case total RAC (see Table 3.1). However, these changes in traffic growth had little impact on the RAC in the early years of the analyses as shown by Figure 3.1 where any significant departure of the cumulative RAC from the base case does not occur until after 2030.

In parallel with the traffic growth scenarios is the potential need for increases in traffic capacity achieved by means of additional lanes. Because the RAC had minor changes due to traffic growth changes in the first four years, it can be inferred that no significant expenditure would be needed for additional lanes. This outcome is based on the assumption that any current need for additional lane capacity at the start of the analysis period would be addressed during year one of the four-year FLCB CAPEX estimates.

Figure 3.1: Total cumulative RAC for the traffic growth scenarios



3.1.3 IMPACT ON NETWORK CONDITIONS

During the life-cycle of the network, conditions change in response to traffic, climate and annual funding. Figure 3.2 shows the distribution of roughness, in cumulative percentile terms, for the whole road network from the commencement to the end of the 30-year analysis using the ARRB PLCC model with 13 240 road segments representing the network. The limits of the roughness condition are adhered to with reference to the Table 2.4 limits on levels of service with the maximum roughness reaching its acceptable limit of 5.33 IRI.

Figure 3.2, Figure 3.2 and Figure 3.3 show the distribution of roughness for the urban freeways, rural major arterials and rural other arterials respectively. The roughness distribution for urban freeways is contained to the limit of 3.45 IRI in Table 2.4. Similarly, the roughness distribution on the rural major arterials and rural other arterials is contained to the maximum roughness limit of 5.33 IRI. As expected, the median roughness on the rural other arterials is higher than that for the rural major arterials.

Figure 3.2: Roughness distribution for whole network over 30-year analysis

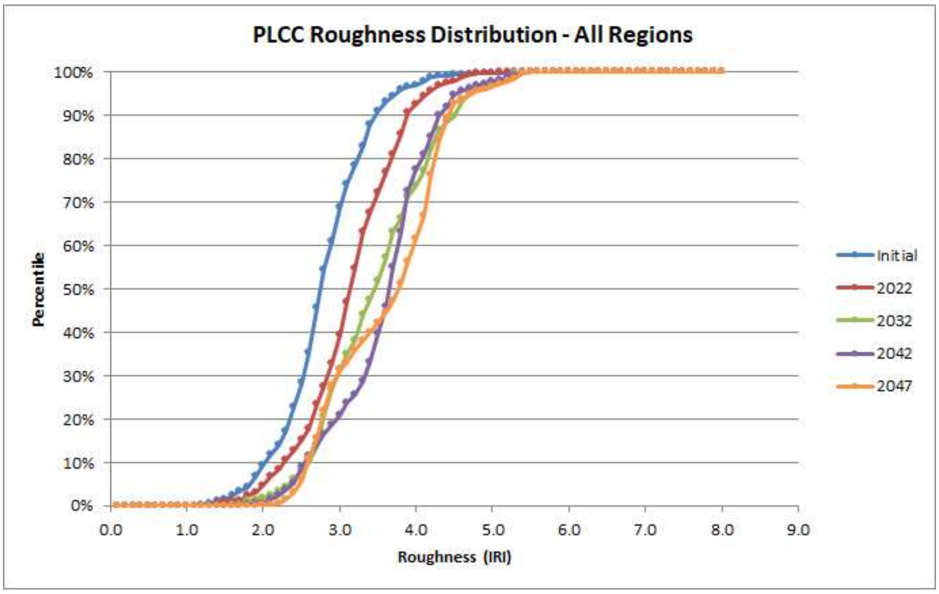


Figure 3.3: Roughness distribution for urban freeways over 30-year analysis

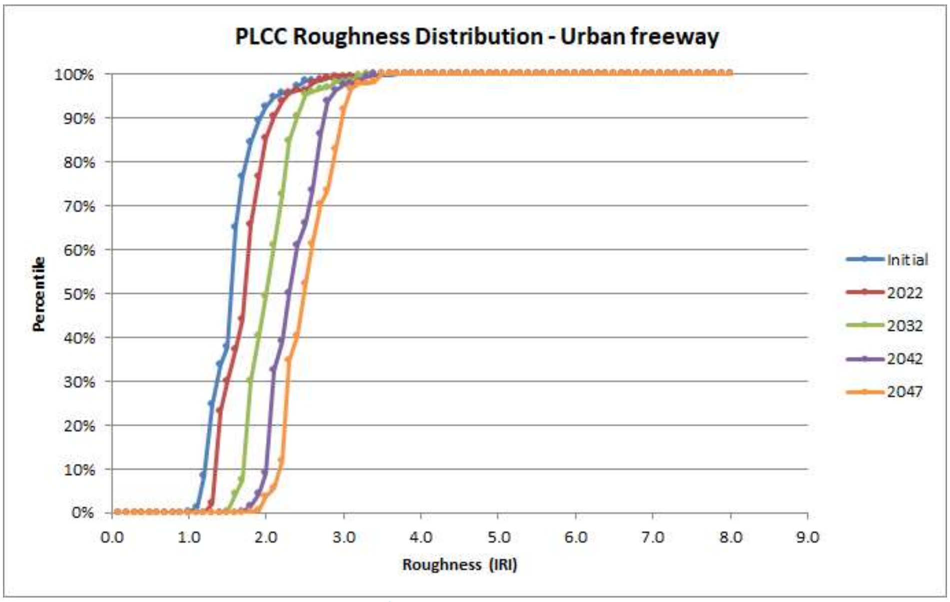


Figure 3.4: Roughness distribution for rural major arterials over 30-year analysis

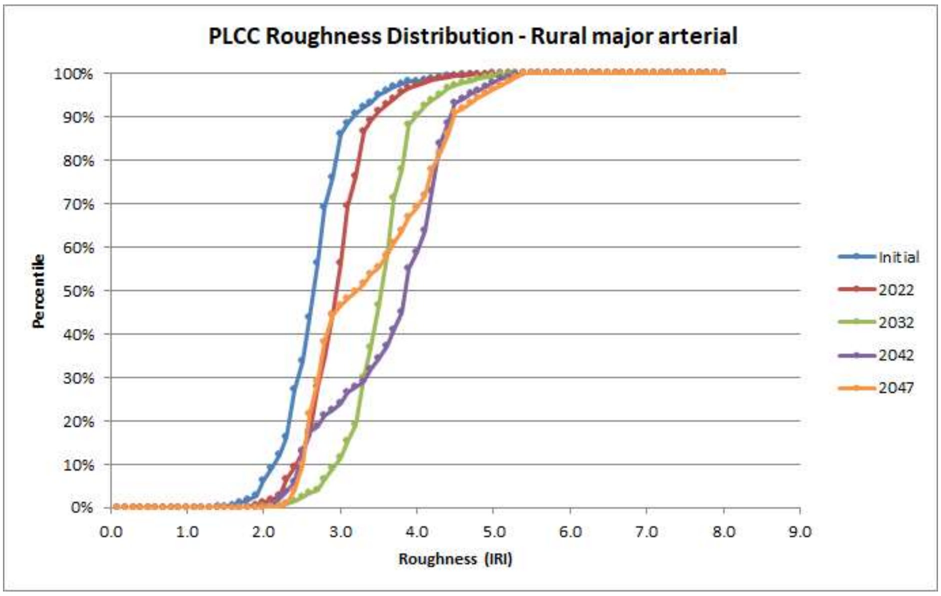


Figure 3.5: Roughness distribution for rural other arterials over 30-year analysis

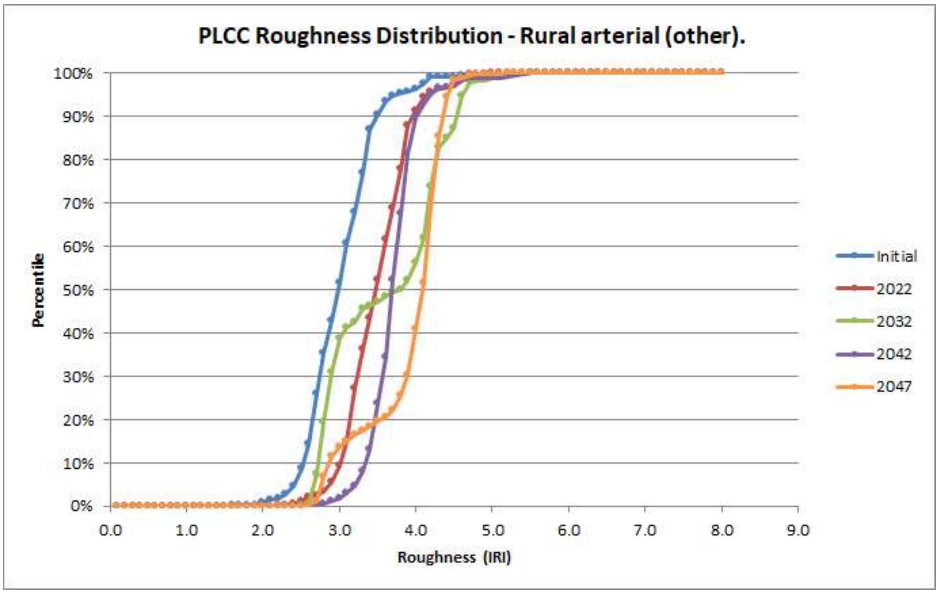


Figure 3.2, Figure 3.2 and Figure 3.3 generally show that the roughness on the arterial road network, and the various arterial road types, is increasing over the 30-year analysis period, although it is within the roughness IRI limits set for each arterial road type. This is due to the effect shown in Figure 2.3 where major maintenance works, such as rehabilitation, do not return the pavement to its original condition (roughness) post construction.

3.2 FLCB FOUR YEAR OPERATING AND CAPEX EXPENDITURES

Table 3.2 summarises the first four years of CAPEX and operating expenditure for the arterial road network derived from the 2018–19 dTIMS analysis using the 104 000 road segments representing the network.

Table 3.2: Summary of FLCB four-year expenditures (2018–19 dTIMS analysis)

Arterial road type	Cost category	Year of FLCB expenditure				
		2018	2019	2020	2021	2022
Urban freeway	Periodic maintenance (CAPEX)	$77 256 982	$1 129 542	$40 685 415	$2 883 589	$1 013 674
	Rehabilitation (CAPEX)	$29 567 752	$4 466 179	$882 391	$216 750	$35 948
	Routine maintenance (Operating)	$1 409 812	$1 411 614	$1 413 935	$1 424 937	$1 428 298
	Total	$108 234 546	$7 007 334	$42 981 740	$4 525 276	$2 477 920
Urban major arterial	Periodic maintenance (CAPEX)	$161 377 099	$10 186 245	$56 826 318	$8 617 847	$5 399 373
	Rehabilitation (CAPEX)	$136 279 071	$3 505 820	$1 999 330	$1 865 933	$483 338
	Routine maintenance (Operating)	$4 129 799	$4 136 178	$4 146 695	$4 173 603	$4 177 762
	Total	$301 785 968	$17 828 242	$62 972 343	$14 657 383	$10 060 473
Urban other arterial	Periodic maintenance (CAPEX)	$384 869 722	$38 623 100	$51 789 122	$25 486 837	$29 942 674

Arterial road type	Cost category	Year of FLCB expenditure				
		2018	2019	2020	2021	2022
	Rehabilitation (CAPEX)	$261 875 695	$9 579 898	$7 630 790	$2 976 164	$622 403
	Routine maintenance (Operating)	$7 886 714	$7 926 598	$7 941 288	$7 984 152	$8 022 608
	Total	$654 632 131	$56 129 596	$67 361 200	$36 447 154	$38 587 686
Rural freeway	Periodic maintenance (CAPEX)	$161 395 749	$13 376 165	$26 147 996	$12 345 807	$15 867 836
	Rehabilitation (CAPEX)	$52 436 669	$1 630 458	$1 033 729	$2 681 669	$526 750
	Routine maintenance (Operating)	$5 195 484	$5 210 705	$5 214 429	$5 223 328	$5 255 250
	Total	$219 027 902	$20 217 328	$32 396 154	$20 250 804	$21 649 836
Rural major arterial	Periodic maintenance (CAPEX)	$544 085 921	$75 292 615	$106 760 091	$61 166 106	$63 853 618
	Rehabilitation (CAPEX)	$194 100 846	$8 230 209	$8 090 983	$18 869 088	$12 950 068
	Routine maintenance (Operating)	$24 273 698	$24 359 750	$24 432 997	$24 476 493	$24 584 017
	Total	$762 460 464	$107 882 574	$139 284 071	$104 511 687	$101 387 703
Rural other arterial	Periodic maintenance (CAPEX)	$970 062 697	$112 201 778	$136 927 827	$101 184 006	$78 810 406
	Rehabilitation (CAPEX)	$581 160 588	$20 006 453	$30 616 282	$19 436 735	$21 019 168
	Routine maintenance (Operating)	$39 779 842	$39 869 033	$39 962 485	$40 141 828	$40 282 154
	Total	$1 591 003 127	$172 077 264	$207 506 593	$160 762 569	$140 111 728
	CAPEX total	$3 554 468 791	298 228 462	$469 390 273	$257 730 533	$230 525 256
	Operating total	$82 675 348	82 913 878	$83 111 828	$83 424 341	$83 750 088
	Grand total	$3 637 144 138	381 142 340	$552 502 101	$341 154 873	$314 275 345

As noted in Section 3.1.2, no CAPEX expenditure on additional lane capacity was needed for the four years of the FLCB.

3.2.1 ANALYSIS OF OUTCOMES

Under the unconstrained budget in the 2018–19 dTIMS analysis, it appears from the magnitude of the first year of expenditure (2018) in Table 3.3 that the analysis has attempted to redress any past deficiencies in road conditions in that year. This is usually referred to as a maintenance backlog, and is further explained in Section 3.1.1. The 2018 expenditure is nearly 10 times that of the 2019 expenditure. This also occurred with the ARRB PLCC analysis as the 2018 expenditure was over 8 times that of the 2019 expenditure (see Figure 3.6), although the annual expenditures in these earlier years were substantially lower than those estimated by the 2018–19 dTIMS analysis.

The different expenditure profile from the ARRB PLCC analysis is mainly due to the coarser segmentation of the network, which tends to average out the higher distress conditions which would have initiated a maintenance response from the 2018–19 dTIMS analysis. This also tends to result in more intervention by rehabilitation, a relatively costly activity, which is deferred as long as possible which is reflected in the ARRB PLCC analysis outcome as shown in Figure 3.6. Figure 3.6 also shows a high expenditure in 2018 relative to the following three years in the FLCB.

Figure 3.6: Arterial road network 30-year annual expenditure profile (ARRB PLCC analysis)

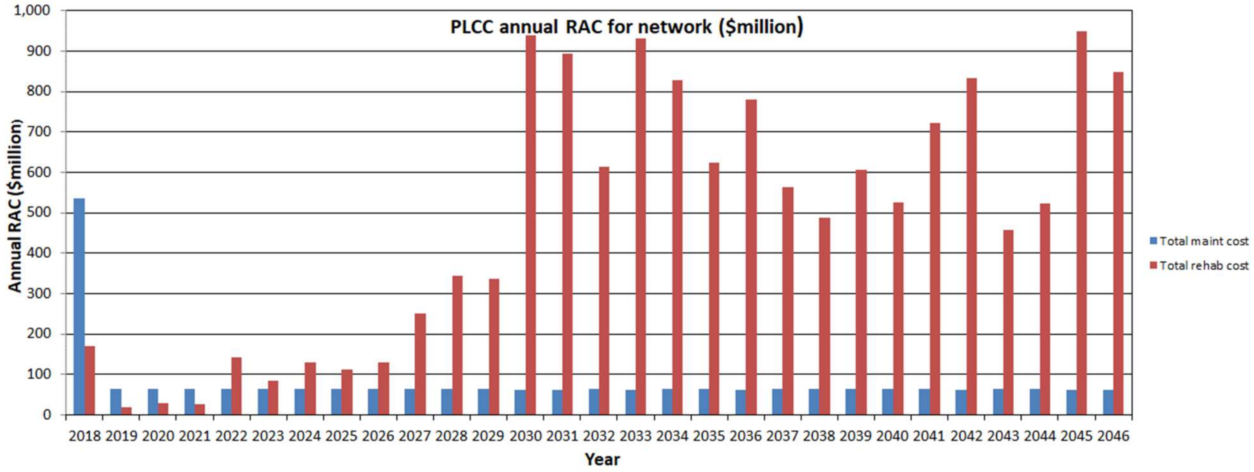


Figure 3.7 shows the 2018–19 dTIMS analysis annual RAC estimates, excluding the off pavement routine maintenance, over the 30-year analysis period. The estimated interval between rehabilitations on the six road types is summarised in Table 3.3. All these rehabilitations occurred on the ‘weak’ road segments.

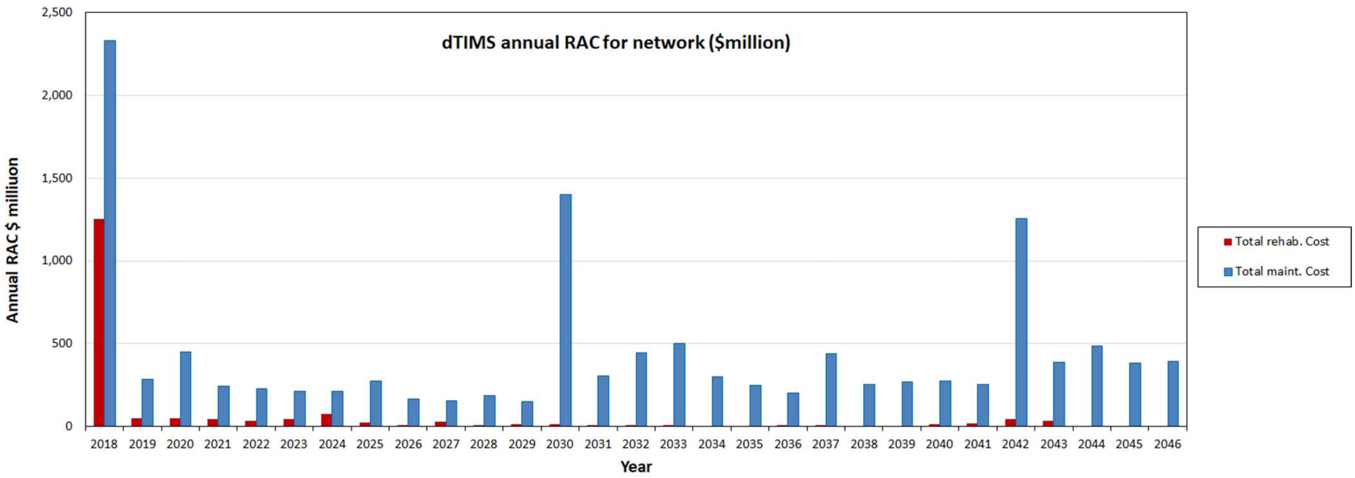
Table 3.3: 2018–19 dTIMS analysis rehabilitation intervals

Road type	Rehabilitation interval range (years)	Mean rehabilitation interval (years)
Urban freeway	13–24	19
Urban major arterial	16–23	19
Urban other arterial	–	–
Rural freeway	23–24	24
Rural major arterial	21–23	22
Rural other arterial	–	–

In contrast to the ARRB PLCC analysis, there is substantially more maintenance expenditure, this comprising the sum of routine pavement maintenance and periodic maintenance, than rehabilitation expenditure over the whole analysis period. This means maintenance works is used to either substantially reduce deterioration and or to frequently reduce the roughness and rutting distresses by intensive surface maintenance works so that it effectively behaves like a rehabilitation over time.

Considering both Figure 3.6 and figure 3.7, the total annual expenditure is the sum of the two columns, and this is required to meet service levels.

Figure 3.7: Arterial road network 30-year annual expenditure profile (dTIMS analysis)



BASIS FOR ESTIMATING RENEWAL CAPEX FOR THE FOUR-YEAR FLCB

It is critical that the pavement life-cycle costing analysis tools are reliable and accurately represent the reality of network pavement performance and maintenance management practice.

The substantially different estimates from using the 2018–19 dTIMS analysis and the ARRB PLCC analysis warrant some consideration, even though their total life-cycle costs for RAC and its PV were relatively similar as shown in Table 3.1.

The 2018–19 dTIMS analysis software is also used by Australasian road agencies for their pavement management systems (PMS). In this application it is a relatively accurate model of the Victorian arterial road network comprising some 104 000 road segments where variations in conditions are reflected in the model so that maintenance and rehabilitation activities can be initiated. In the ARRB PLCC analysis, the reduced number of road segments (13 240) causes averaging of the extreme condition distress values with the result of less maintenance and rehabilitation activities initiated in the early stages of the analysis. Figure 3.6 of the ARRB PLCC expenditure profile shows major rehabilitations occurring in the middle of the 30-year analysis period.

The 2018–19 dTIMS analysis outcomes are considered to be more reliable than those of the ARRB PLCC analysis, which essentially was used to quantify the impact of low and high traffic growth scenarios on the network life-cycle costs for RAC.

TREATMENT OF RENEWAL CAPEX FOR THE FIRST YEAR OF THE FLCB

The large CAPEX renewal expenditure ($3 554 468 791) for the first year of the four-year FLCB, as estimated by the 2018–19 dTIMS analysis (see Table 3.2), is well beyond the capacity of industry to undertake in a single year. Consequently, this will need to be distributed over the four years of the FLCB. Table 3.4 shows an example of how the CAPEX could be distributed and the resulting aggregated revised four-year FLCB.

Table 3.4: Redistributed four-year FLCB

Expenditure type	2018	2019	2020	2021	Total 4 year
Estimated CAPEX total	$3 554 468 791	$298 228 462	$469 390 273	$257 730 533	$4 579 818 058
Distribution of year 1 CAPEX – across following 3 years	$1 184 822 930	$789 881 953	$789 881 953	$789 881 953	$3 554 468 791
Est. periodic maintenance	$1 255 420 622				
Est. rehabilitation	$2 299 048 168				

Expenditure type	2018	2019	2020	2021	Total 4 year
Distributed periodic maint.	$418 473 541	$278 982 360	$278 982 360	$278 982 360	$1 255 420 622
Distributed rehab.	$766 349 389	$510 899 593	$510 899 593	$510 899 593	$2 299 048 168
Periodic maintenance		$47 419 017	$50 253 505	$46 046 340	
Rehabilitation		$250 809 444	$419 136 768	$211 684 192	
Operating total	$82 675 348	$82 913 878	$83 111 828	$83 424 341	
Revised grand total	$1 267 498 278	$1 171 024 293	$1 342 384 055	$1 131 036 827	$4 911 943 453
Original grand total	$3 637 144 138	$381 142 340	$552 502 101	$341 154 873	$4 911 943 453

The distribution approach used was to divide the first year of CAPEX by three and distribute the remaining two thirds of the first year CAPEX equally across the other three years of the FLCB. Consideration could be given to distributing the first year CAPEX across more years beyond the fourth year of the FLCB to further reduce the ‘lumpiness’ of the expenditures.

4 CONCLUSIONS

This report documents the ARRB estimates of the following expenditures for the first four years of the FLCB:

- The annual routine maintenance, including both off pavement and pavement-related expenditures, that form part of the operating expenditure of the annual revenue requirements (ARR) component of the FLCB.
- The periodic maintenance and rehabilitation expenditures of pavements that form part of the annual renewal component of the CAPEX. No significant expenditure on additional lanes for increased traffic capacity was found to be necessary for the first four years of the FLCB, apart from what may have been allowed in the forward CAPEX estimates.

The impact of low (1%) and high (3%) annual traffic growth scenarios on the operating and CAPEX expenditures was estimated and was found not to be significant for the first four years of the FLCB.

The estimates of annual operating and renewal (CAPEX) expenditures were based on a 2018–19 dTIMS pavement life-cycle costing (PLCC) analysis of the Victorian arterial road network over a 30-year period with a medium (2%) annual traffic growth rate. The ARRB PLCC analysis was used to examine the impact of the low and high annual traffic growth scenarios on the annual operating and CAPEX expenditures.

All the expenditures from the above PLCC analysis were under unconstrained budgetary conditions. Appendix C details the estimated annual CAPEX and operating expenditures for the Victorian arterial road network over the 30-year analysis period. Table 3.3 summarises the estimated annual CAPEX and operating expenditures for the first four years of the FLCB. It should be noted that the methodology adopted for this study produces upper bound (high) estimates of the expenditures due to the unconstrained budgetary conditions.

Further discussion regarding the basis of the ARRB estimates is outlined below.

4.1 NETWORK DATA LIMITATIONS

In Section 2.1 several of the road use variables for both cost allocation and the PLCC analyses were based on average estimates of heavy vehicle characteristics across the arterial road network. Some further study is advised to ensure that these heavy vehicle characteristics are representative for the six road types as they influence both the expenditure estimates from the PLCC analyses and the outcomes of the previous 2017 ARRB cost allocation matrix.

PAVEMENT AGE

This variable was estimated from the roughness measurements taken along each of the six road types. The estimation also required an assessment of what the initial roughness post-construction would be for the different road types. The pavement age (AGE) variable is also an important variable in predicting pavement performance as it is related to the various form of pavement distress such as roughness, rutting (permanent deformation) and loss of pavement strength. If information about when pavements were constructed and rehabilitated is known, it is possible to derive accurate and reliable estimates of pavement AGE. This is currently a deficiency of the VicRoads database, because the AGE variable influences pavement performance and consequently the expenditure estimates from the PLCC analyses.

PAVEMENT STRENGTH SNC_0

The estimates of pavement strength, SNC_0, were based on the strength value needed to carry the estimated design traffic load/lane, which in turn was based on assessment of the current traffic load. The SNC_0 variable is an important variable in predicting pavement performance as it is related to the various forms of pavement distress such as roughness and rutting. It is now possible to safely and directly measure pavement strength at highway speed using the Traffic Speed Deflectometer (TSD) across the road network. It is understood that strength varies significantly across the network and is not always related to the design traffic load. This is also a current deficiency of the VicRoads database because the SNC_0 variable influences pavement performance and, consequently, the expenditure estimates from the PLCC analyses.

4.2 BASIS FOR ESTIMATING RENEWAL CAPEX EXPENDITURE FOR THE FOUR-YEAR FLCB

The 2018–19 dTIMS PLCC 30-year analysis of the Victorian arterial road network was considered to be the most appropriate basis for estimating the first four years CAPEX and operating expenditures for the FLCB. This is because it is a relatively more accurate and reliable estimate based on 104 000 road segments compared to the 13 240 road segments used by the ARRB PLCC analysis.

The 2018–19 dTIMS analysis software is also used by some Australasian road agencies for their pavement management systems (PMS). Consequently, it has credibility with many of the stakeholders. It is critical that the pavement life-cycle costing analysis tools are reliable and accurately represent the reality of network pavement performance and maintenance management practices to produce credible expenditure estimates for the FLCB.

4.3 TREATMENT OF RENEWAL CAPEX FOR THE FIRST YEAR OF THE FLCB

The large CAPEX renewal expenditure for the first year of the four-year FLCB, as estimated by the 2018–19 dTIMS analysis, is well beyond the capacity of industry to undertake in a single year. Consequently, this needs to be distributed over the four years of the FLCB.

The distribution approach used divided the first year of CAPEX by three and distributed the remaining two thirds of the first year CAPEX equally across the other three years of the FLCB. Consideration could be given to distributing the first year CAPEX across more years beyond the fourth year of the FLCB to further reduce the 'lumpiness' of the expenditures.

4.4 COST ALLOCATION MATRIX

The cost allocation matrix developed in 2017 (Martin 2017b) depends to a large extent on the road use parameters that apply to each of the six road types used to represent the Victorian arterial road network. Some of the relatively minor changes to road use that were used in this study also resulted in minor changes to the cost allocation matrix (see Table B 1).

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Appendix A VICTORIAN NETWORK AND ROAD USE DATA

A.1 Victorian Arterial Road Network and Road Use

Table A 1 summarises the road length (km), lane-km and mean number of lanes for each of the roads in each of the VicRoads Regions. Also included are the various measures of road use, such as the annual vehicle kilometres travelled (VKT), and annual heavy vehicle road use measures, such as, VKT, ESA-km, GVM-km and PCU-km, which are used for cost allocation of the costs from the FLCB. The second column has the road lengths (km) used in the earlier study (Martin 2017) which have been revised upwards for the current study in column 5 using the latest available data.

Table A 1: Summary of Victorian arterial network and road use data

Road type	Original distance (km)	%CV[1]	TMI[2]	Revised distance (km)	Annual VKT[3]	Annual HV VKT[4]	Annual HV ESA-km[5]	Annual HV GVW-km[6]	Annual HV PCU-km[7]	Lane-km	Lane-km asphalt AC	Lane-km gran. GN	Lane-km other	Mean no. lanes
Freeway/hwy – urban														
METRO NORTH WEST	189.1	9.8	3.2	0.6						1027.5	1027.5	0		5.44
METRO SOUTH EAST		9.0	48.9	0.4						690.2	690.2	0		4.54
Total =	**341.0**	**9.4**	**23.6**	391.0	**5 447 411 929**	**514 428 801**	**1 303 591 468**	**10 729 147 888**	**1 388 957 763**	**1 717.7**	1 717.7	0.0	0.0	**5.04**
Major road urban														
METRO NORTH WEST	96.9	5.3	–7.1	0.2						497.5	497.5	0.0		5.13
METRO SOUTH EAST	418.1	5.6	29.8	0.8						2049.0	2049.0	0.0		4.90
Total =	**515.1**	**5.5**	**22.8**	1 174.7	**6 957 732 697**	**385 704 869**	**481 681 301**	**3 964 455 149**	**771 409 738**	**2 546.5**	2 546.5	0.0	0.0	**4.94**
Other road urban														
METRO NORTH WEST	825.4	6.4	–5.0	0.4						2757.2	1763.4	971.7	22.1	3.34
METRO SOUTH EAST	1 532.0	5.9	25.9	0.6						4127.0	1340.0	2649.5	137.5	2.69

Road type	Original distance (km)	%CV(1)	TMI(2)	Revised distance (km)	Annual VKT(3)	Annual HV VKT(4)	Annual HV ESA-km(5)	Annual HV GVW-km(6)	Annual HV PCU-km(7)	Lane-km	Lane-km asphalt AC	Lane-km gran. GN	Lane-km other	Mean no. lanes
Total =	2 357.4	**6.1**	**15.1**	2 939.6	**8 717 963 777**	**529 622 392**	**1 187 376 793**	**9 772 648 499**	**1 324 055 980**	6 884.2	3 103.4	3 621.2	159.6	**2.92**
Urban Grand Total =	3 213.5			4 505.3						**11 148.4**				
Freeway/hwy – rural														
EASTERN	65.2	12.1	20.6	0.13						252.3	167.5	84.8		3.87
NORTH EASTERN	194.5	26.9	–5.8	0.39						979.4	187.9	791.3		5.04
NORTHERN	157.9	17.3	–15.9	0.31						711.9	319.7	392.2		4.51
SOUTH WESTERN	17.5	11.6	–10.6	0.03						273.1	273.1	0		5.00
WESTERN	69.8	15.8	8.2	0.14						385.6	346.6	39		5.52
Total =	505.0	**19.9**	**–3.8**	1 005.4	**2 324 794 436**	**463 117 274**	**1 129 948 197**	**9 299 985 158**	**1 343 040 095**	2 602.4	1 294.8	1 307.3	0.0	**4.79**
Major road rural														
EASTERN	895.8	10.1	41.4	0.16						2020.2	0.0	2020.2		2.26
NORTH EASTERN	777.5	9.6	44.8	0.14						2067.6	0	2067.6		2.66
NORTHERN	1 302.8	11.3	–26.5	0.23						2967.4	0.0	2967.4		2.28
SOUTH WESTERN	902.0	11.4	10.0	0.16						2422.6	590.3	1832.3		2.69
WESTERN	1 703.9	11.5	–29.8	0.31						3640.5	0.0	3640.5		2.14
Total =	5 582.0	**10.9**	**–0.8**	6 329.9	**5 117 166 485**	**560 218 820**	**1 488 457 396**	**12 805 961 302**	**1 512 590 813**	13 118.3	590.3	12 528.0	0.0	**2.35**

Road type	Original distance (km)	%CV[1]	TMI[2]	Revised distance (km)	Annual VKT[3]	Annual HV VKT[4]	Annual HV ESA-km[5]	Annual HV GVW-km[6]	Annual HV PCU-km[7]	Lane-km	Lane-km asphalt AC	Lane-km gran. GN	Lane-km other	Mean no. lanes
Other road rural														
EASTERN	1 897.7	7.9	11.9	0.17						4676.4	0.0	4379.0	297.4	2.46
NORTH EASTERN	2 103.5	9.3	31.3	0.19						4514.7	0.0	4340.4	174.7	2.15
NORTHERN	2 144.2	7.5	–27.0	0.20						4619.9	0.0	4619.9	319.8	2.15
SOUTH WESTERN	2 123.8	8.9	–0.7	0.19						5736.0	0.0	5696.4		2.70
WESTERN	2 629.9	8.1	–21.6	0.24						5546.2	0.0	5545.4		2.11
Total =	10 899.1	**8.3**	**–2.5**	12 242.2	**3 622 876 083**	**301 953 069**	**845 468 594**	**6 958 589 253**	**815 273 287**	25 093.3	0.0	24 581.1	791.9	**2.30**
Rural Grand Total =	16 986.0			19 577.5						40 813.9				
Grand Total	**20 199.5**			**24 083**	**32 187 945 407**	**2 755 045 225**	**6 436 523 749**	**53 530 787 248**	**7 155 327 676**	**51 962.4**				

1 *%CVs = percentage of commercial vehicles.*
2 *TMI = Thornthwaite Moisture Index (climate).*
3 *Annual VKT = annual vehicle kilometres travelled.*
4 *Annual HV VKT = annual heavy vehicle kilometres travelled.*
5 *Annual HV ESA-km = annual heavy vehicle equivalent standard axle (ESA) kilometres travelled.*
6 *Annual HV GVM-km = annual heavy vehicle gross vehicle mass kilometres travelled.*
7 *Annual HV PCU-km = annual heavy vehicle passenger car unit kilometres travelled.*

Table A 2 summarises the cost allocation parameters for each of the six arterial road types.

Table A 2: Summary of Victorian arterial network road use parameters for cost allocation

Road type	AADT total	No axles /HV	ESA/ HVAG[1]	AADT/ lane	ESA/ HV[2]	GVM/ HV[3]	PCU/ HV[4]	MESA/ lane/yr[5]	Pavement AGE[6] (years)	NRM[13] (IRI)[14]	Design MESA[7]	SNC_0[8]	TMI	ta[9]	tg[10]	% load main.[11]	% load cons.[12]
Freeway/ hwy – urban																	
METRO NORTH WEST		2.81	1.06		2.98	24.52	2.9										
METRO SOUTH EAST		2.79	0.71		1.98	16.30	2.5										
Total =	**38 166**			**7 576**	**2.53**	**20.86**	**2.7**	**1.08**	7	49 (1.96)	72.04	7.3	24	330	577	70.8	86.2
																(70)	(85)
Major road urban																	
METRO NORTH WEST		2.26	0.70		1.58	13.02	2										
METRO SOUTH EAST		2.90	0.40		1.17	9.64	2										
Total =	**16 227**			**3 282**	**1.25**	**10.28**	**2.0**	**0.13**	11	60 (2.40)	17.98	6.3	23	280	517	51.5	84.0
																(50)	(85)
Other road urban																	
METRO NORTH WEST		2.59	0.86		2.23	18.33	2.5										
METRO SOUTH EAST		3.27	0.69		2.25	18.52	2.5										
Total =	**8 125**			**2 782**	**2.24**	**18.45**	**2.5**	**0.20**	27	79 (3.16)	6.43	5.7	15	230	472	56.3	81.3
																(55)	(80)

Road type	AADT total	No axles /HV	ESA/ HVAG[1]	AADT/ lane	ESA/ HV[2]	GVM/ HV[3]	PCU/ HV[4]	MESA/ lane/yr[5]	Pavement AGE[6] (years)	NRM[13] (IRI)[14]	Design MESA[7]	SNC_0[8]	TMI	ta[9]	tg[10]	% load main.[11]	% load cons.[12]
Freeway/ hwy – rural																	
EASTERN		2.85	0.65		1.86	15.29	2.5										
NORTH EASTERN		2.90	0.73		2.12	17.45	2.5										
NORTHERN		3.25	0.77		2.50	20.54	2.5										
SOUTH WESTERN		3.16	1.28		4.04	33.29	4										
WESTERN		3.04	1.10		3.34	27.52	3										
Total =	**6 335**			**1 324**	**2.44**	**20.08**	**2.9**	**0.53**	10	58 (2.32)	28.25	6.6	–4		536	59.6	78.0
																(60)	(80)
Major road rural																	
EASTERN		2.84	0.83		2.37	19.49	2.5										
NORTH EASTERN		3.28	1.14		3.74	22.20	3										
NORTHERN		3.22	0.53		1.71	21.85	2										
SOUTH WESTERN		3.27	0.93		3.04	22.12	3										
WESTERN		3.46	0.82		2.83	26.09	3										
Total =	**2 215**			**942**	**2.66**	**22.86**	**2.7**	**0.12**	13	65 (2.60)	5.43	5.6	–1		465	53.6	69.6
																(55)	(70)

Road type	AADT total	No axles /HV	ESA/ HVAG[1]	AADT/ lane	ESA/ HV[2]	GVM/ HV[3]	PCU/ HV[4]	MESA/ lane/yr[5]	Pavement AGE[6] (years)	NRM[13] (IRI)[14]	Design MESA[7]	SNC_0[8]	TMI	ta[9]	tg[10]	% load main.[11]	% load cons.[12]
Other road rural																	
EASTERN					2.8	23.05	2.7										
NORTH EASTERN					2.8	23.05	2.7										
NORTHERN					2.8	23.05	2.7										
SOUTH WESTERN					2.8	23.05	2.7										
WESTERN					2.8	23.05	2.7										
Total =	**811**			**352**	**2.80**	**23.0**	**2.7**	**0.03**	25	76 (3.04)	0.99	4.7	–3		391	55.2	58.5
																(55)	(60)

1 ESA/HVAG = ESAs per heavy vehicle axle group.
2 ESA/HV = ESAs per heavy vehicle.
3 GVM/HV = GVMs per heavy vehicle.
4 PCU/HV = PCUs per heavy vehicle.
5 MESA/lane/yr. = millions of ESAs of heavy vehicle traffic per lane per year.
6 Pavement AGE (years) = age of pavement either since construction or last rehabilitation, whichever is the lesser.
7 Design MESA = Design traffic load in millions of ESAs per lane over the design life of the pavement.
8 SNC_0 = pavement/subgrade strength immediately post construction.
9 t_a = thickness of asphalt pavement base.
10 t_g = thickness of granular pavement base.
11 % load main. = percentage load related pavement maintenance (wear) costs.
12 % load cons. = percentage load related pavement construction costs.
13 NRM = roughness counts/km.
14 IRI = International Roughness Index (m/km).

Appendix B UPDATED COST ALLOCATION MATRIX

Table B 1: Updated cost allocation matrix

Cost category	Location	Road class	Load-related cost		Non-load-related cost	
			%(1)	Parameter(2)	%(1)	Parameter(2)
Pavements – new, extra lanes and replacement	Urban	Freeways and major highways	85	ESA-km	15	VKT
		Main arterials	85	ESA-km	15	VKT
		Other arterials	80	ESA-km	20	VKT
	Rural	Freeways and major highways	80	ESA-km	20	VKT
		Main arterials	70	ESA-km	30	VKT
		Other arterials	60	ESA-km	40	VKT
Associated pavement facilities (new/replacement) – shoulders, kerbs, drains, earthworks, etc.	Urban	Freeways and major highways	5	PCU-km	95	VKT
		Main arterials	0		100	VKT
		Other arterials	0		100	VKT
	Rural	Freeways and major highways	10	PCU-km	90	VKT
		Main arterials	5	PCU-km	95	VKT
		Other arterials	5	PCU-km	100	VKT
Bridge superstructure – new, extra lanes and replacement	All	All	15	PCU-km	85	VKT
Bridge superstructure – deck rehabilitation or replacement and other superstructure rehabilitation	All	All	30	PCU-km	70	VKT
Bridge substructure – new, rehabilitation and replacement	All	All	15	GVM	85	VKT
Safety and mobility facilities – new, extra capacity and replacement (traffic signals, signage, barriers, etc.)	Urban	Freeways and major highways	10	PCU-km	90	VKT
		Main arterials	5	PCU-km	95	VKT
		Other arterials	5	PCU-km	95	VKT
	Rural	Freeways and major highways	5	PCU-km	95	VKT
		Main arterials	5	PCU-km	95	VKT
		Other arterials	0	PCU-km	100	VKT

Cost category	Location	Road class	Load-related cost		Non-load-related cost	
			%[1]	Parameter[2]	%[1]	Parameter[2]
Pavements – rehabilitation (structural)	Urban	Freeways and major highways	70	ESA-km	30	VKT
		Main arterials	50	ESA-km	50	VKT
		Other arterials	55	ESA-km	45	VKT
	Rural	Freeways and major highways	60	ESA-km	40	VKT
		Main arterials	55	ESA-km	45	VKT
		Other arterials	55	ESA-km	45	VKT
Pavements – periodic maintenance (resealing, surface correction, heavy patching, resurfacing)	Urban	Freeways and major highways	70	ESA-km	30	VKT
		Main arterials	50	ESA-km	50	VKT
		Other arterials	55	ESA-km	45	VKT
	Rural	Freeways and major highways	60	ESA-km	40	VKT
		Main arterials	55	ESA-km	45	VKT
		Other arterials	55	ESA-km	45	VKT
Pavements – routine maintenance (minor patching, drainage maintenance, pothole repairs, shoulder repairs & regrading, crack sealing, etc.)	All	All	10	PCU-km	90	VKT
Bridges (super and substructure) – minor repairs, repainting, etc.	All	All	0		100	VKT
Safety and mobility facilities – maintenance of traffic signals, signage, barriers, etc.	All	All	0		100	VKT

1 *%s are values from VicRoads data rounded to the nearest 5%.*

2 *Parameters are based on this review.*

Appendix C VICTORIAN ARTERIAL ROAD 30-YEAR EXPENDITURE ESTIMATES

Table C 1: Victorian arterial road network 30-year estimated CAPEX and operating expenditures ($)

Treatment	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Regulate AC	337 720 532	20 103 344	19 222 006	16 100 940	15 294 440	8 020 633	5 546 896	6 319 927	3 162 801	4 079 437	11 951 820	7 516 612	19 828 767	16 784 476
Regulate SS	948 288 593	59 802 212	63 654 837	60 514 940	68 387 627	44 725 999	35 821 590	181 085 059	87 792 687	89 672 011	111 169 230	106 126 348	110 664 053	107 162 206
Rehab. AC	477 722 191	21 500 632	15 889 737	4 910 406	179 798	171 137	133 260		6 318		1 922 082	4 970 147	6 636 042	2 336 395
Rehab. SS	777 698 431	25 918 385	34 363 767	41 135 934	35 457 878	44 838 495	74 793 988	22 980 995	9 303 893	30 926 908	6 589 479	8 773 089	8 686 144	6 758 364
Resurf. AC	429 339 376	48 014 649	189 923 463	44 066 853	47 387 858	38 106 221	73 189 464	12 438 190	27 523 370	24 340 668	28 903 768	2 553 014	478 422 677	36 228 737
Resurf. SS	575 999 949	122 885 536	146 336 463	91 001 460	63 817 656	87 003 684	64 231 188	42 768 661	15 380 796	1 073 632	115 314	2 829	760 038 688	110 414 939
Retext. AC	156 749													
Retext. SS	7 542 969	3 703												
Routine mt. (RM)	33 070 139	33 165 551	33 244 731	33 369 736	33 500 035	33 586 182	33 686 682	33 785 897	33 836 916	34 014 655	34 129 082	34 189 977	34 310 100	34 371 583
Off pave. RM	49 605 209	49 748 327	49 867 097	50 054 604	50 250 053	50 379 273	50 530 022	50 678 845	50 755 374	51 021 982	51 193 623	51 284 965	51 465 150	51 557 374
Grand total	3 637 144 138	381 142 340	552 502 101	341 154 873	314 275 345	306 831 624	337 933 090	350 057 573	227 762 156	235 129 294	245 974 398	215 416 980	1 470 051 621	365 614 074

Table C.1 cont'd: Victorian arterial road network 30-year estimated CAPEX and operating expenditures ($)

Treatment	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046
Regulate AC	10 966 852	15 139 118	16 521 840	9 431 717	9 892 548	6 536 605	9 147 026	7 288 537	28 532 032	22 439 026	49 194 322	52 096 983	68 456 660	38 942 471	43 616 746
Regulate SS	124 953 062	126 517 120	135 409 451	57 235 577	33 636 330	296 863 525	153 479 844	158 495 712	160 636 021	155 988 202	152 341 028	148 701 830	175 352 976	181 976 743	199 956 297
Rehab. AC	408 105	1 611 585	1 339 248	440 160	2 475 992	3 601 672	85 077	234 303	8 792 280	9 128 255	37 092 969	34 661 227	4 007 366	589 260	1 055 457
Rehab. SS	8 516 163	7 038 699	3 673 491	573 869	3 630 562	2 632 070	3 623 402	2 683 467	5 790 106	8 231 538	5 912 045	822 647	968 253	440 819	1 409 599
Resurf. AC	139 153 953	241 320 448	47 773 723	69 682 013	58 942 186	30 773 940	25 612 896	44 005 803	24 273 446	15 253 878	450 394 939	50 128 438	89 832 044	32 957 685	23 405 849
Resurf. SS	135 000 475	86 410 499	67 427 448	79 213 584	64 521 522	71 093 149	31 400 692	23 975 094	24 882 027	24 747 931	568 426 138	99 505 140	118 805 956	93 159 100	87 992 767
Retext. AC															

Treatment	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046
Retext. SS															
Routine mt. (RM)	34 472 525	34 620 216	34 687 378	34 783 203	34 937 416	35 052 318	35 223 229	35 381 508	35 484 079	35 687 664	35 788 918	35 865 978	35 960 613	36 160 742	36 231 991
Off pave. RM	51 708 788	51 930 324	52 031 067	52 174 805	52 406 124	52 578 477	52 834 844	53 072 262	53 226 119	53 531 495	53 683 376	53 798 966	53 940 920	54 241 113	54 347 987
Grand total	505 179 922	564 588 008	358 863 645	303 534 929	260 442 680	499 131 757	311 407 010	325 136 686	341 616 110	325 007 987	1 352 833 735	475 581 208	547 324 787	438 467 932	448 016 692

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