WARRIP
WESTERN AUSTRALIAN ROAD RESEARCH AND INNOVATION PROGRAM

2020-002 Heavy Vehicle Impacts Cost Estimation Processes and Fund Allocation: Technical Report

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5	3/03/2021	Ulysses Ai	Progress Report with full network analysis for PM review
6	30/06/2021	Ulysses Ai	Final Technical Report covering full scope

SUMMARY

This project was undertaken to provide a defensible approach to managing the Western Australian arterial road network to agreed standards under unexpected or increasing heavy vehicle loads.

In order to be defensible, the final recommended approach must be based on proven tools, models and approaches and be relevant to road types and environments found in Western Australia. However, this did not preclude examining literature from elsewhere in Australia or internationally.

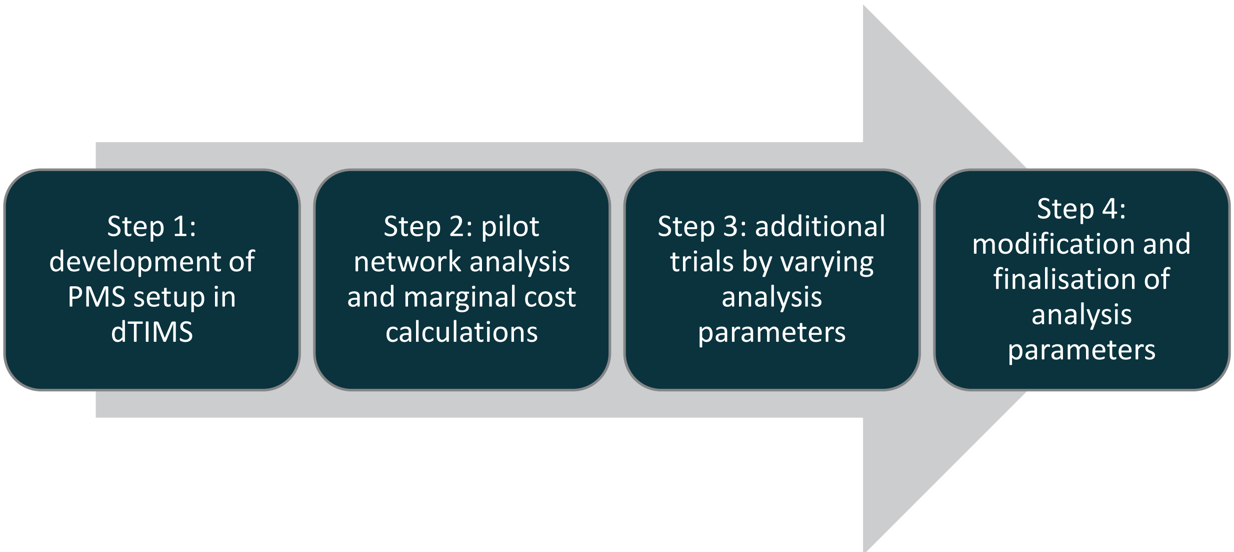
This Final Technical Report presents the setup of the analysis tools and inputs, the results of the marginal cost analysis across the whole MRWA arterial network, and the results of investigations into benefits to heavy vehicle operators where a well-managed road network and corresponding road preservation funding is at an appropriate level and directed to where it is needed.

Analysis tools and Parameters

Determination of marginal cost required long term analysis of pavement performance (50 years for the current work) with provision for road pavement treatments in response to various loading scenarios. So, the capabilities and functionalities of the available life cycle costing (LCC) tools options (FAMLIT, PLCCDT, DTIMS) were considered in relation to the required outcomes of the project and dTIMS with some modifications was selected as the best tool for the analysis.

The development of the LCC analysis setup for this project was a continual process where the initial setup in dTIMS was prepared at the beginning of the analysis through implementation of deterioration models, treatments, LOS, etc. However, over time, various parameters were modified based on the outputs of preliminary pilot network analysis and findings from different trialled approaches. The whole process can be broadly categorised into 4 steps as illustrated in Figure i.

Figure i: LCC setup development and modifications over time



The analysis included incorporating additional considerations related to treatments and costs, with these aimed at accounting for remaining asset life beyond the period of the analysis, and where minimum treatment intervals meant that a higher cost treatment was required when the trigger was exceeded. This was achieved by incorporating calculations of asset consumption/salvage value and penalty costs in the dTIMS model. The process for generating the marginal cost from the full network analysis results (50-year life cycle analysis) was as follows:

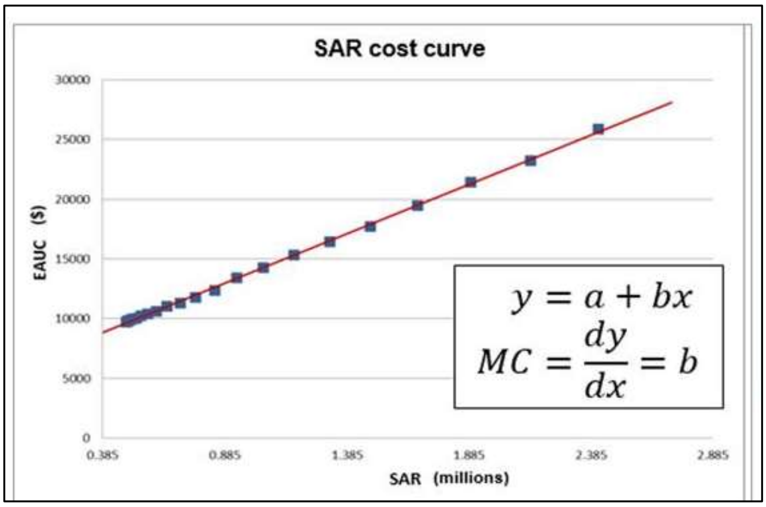
1. Extract the year-by-year road agency cost (RAC) stream for each segment

2. Add asset consumption cost to the final year RAC and a penalty cost to a delayed treatment.
3. Derive a discounted present value cost (PV_RAC) for the full analysis period.
4. Compute the equivalent annual uniform cost (EAUC) where EAUC discount rate=7%

$$\boldsymbol{EAUC} = (\boldsymbol{PV\_RAC} * \boldsymbol{DiscountRate})/(\mathbf{1} - (\mathbf{1}/((\mathbf{1} + \boldsymbol{DiscountRate})\textasciicircum \boldsymbol{Analysis\ period})))$$

5. Extract the annual number of equivalent standard axles (MESA) for each segment and derive a discounted MESA (PV_MESA) for the full analysis period.
6. Convert PV_MESA to EAUC_MESA using the same formula as the cost calculation.
7. Create a linear regression of EAUC_RAC vs. EAUC_MESA from the results of the three loading scenarios for each segment, as per Figure ii, with the gradient*100 equal to the MC (in cents per ESA.km).

Figure ii: Relationship between EAUC and ESA/SAR



Overview of MRWA Network Data

The road network data used in this analysis was the MRWA network supplied as part of the WARRIP IDM2 project with additional traffic data. This network contains over 180,000 one-hundred-metre segments. However, not all road segments have the surface condition and deflection data collected. Considering the availability of all condition data required for analysis, there was around 15,800 km of valid road length distributed over eight MRWA regions.

More than 90% of the road lengths on each subnetwork consist of sealed surfaces except Metropolitan region where around 70% of the road length is asphalt-surfaced and rest is sealed. Level of service (LOS) definitions and treatment triggers defined in the dTIMS setup vary by MRWA road link category. More than half of the network length sit in either the *Medium-* or *Basic-Standard single carriageway road* category.

The below observations were made after an analysis of the network dataset:

- **Traffic**: Most of the regions have all the road lengths with traffic below 10,000 AADT. Metropolitan and South West region have some lengths with AADT between 10,000-30,000. The Metropolitan region also has a small amount of road length with AADT more than 30,000.
- **Rainfall**: The majority of the regions have all the road lengths within annual rainfall ranges of 200-800 mm. Metropolitan and South West region have substantial road lengths with 800-1200 mm of annual rainfall
- **Deflection**: All regions have almost all lengths with low (<500 microns) to moderate (<1000 microns) mean deflection (Do max/1.3). However, very small proportions of road length in all regions display high mean deflection (>1000 microns).

Thornthwaite Moisture Index (TMI) is an important parameter applied in various places within Austroads deterioration models adopted for the current analysis. TMI was not readily available from the MRWA road database and hence was calculated for the whole network at 1 km intervals using a Climate Tool developed as a part of an earlier Austroads research project, with the spatially plotted TMI values agreeing with TMI area maps of Western Australia.

With the setup steps complete, to efficiently run the analysis within dTIMS, the following measures were taken:

- Due to the size of the network causing run time constraints in dTIMS, separate analysis was done for each region by surface type totalling 9 combinations (8 with region and sealed surface combinations and 1 for all asphalt surfaces within the network).
- For each of these combinations, three analysis runs were undertaken representing three loading scenarios, namely 100%, -40%, and +40% ESA loading based on current (and projected) traffic.
- To avoid generation of excessive amounts of treatments and strategies over the analysis period, a 10-year minimum treatment interval period was applied between successive treatments.
- A 50-year analysis period was used to adequately capture the benefit from treatments.
- An unconstrained funding level was also applied during optimization.

Analysis Output – Marginal Costs

Average MC values for the sprayed seal network grouped by deflection ranges are presented in Table i.

Table i: Average MC values for regions grouped by deflection – sprayed seal network (cents/esa.km)

Deflection	Goldfields Esperence	Great Southern	Kimberley	Metropolitan	Mid-West Gascoyne	Pilbara	South West	Wheatbelt
<500	0.60	0.94	0.47	1.16	0.44	0.58	1.02	0.82
500-1000	1.26	2.30	1.47	1.73	1.33	1.29	2.34	2.20
>1000	1.44	3.96	2.27	5.40	2.43	2.16	5.27	5.15

For the sprayed seal network, it was found that:

- The MC distribution for the network ranges from 0-10 cents/km. For all regions, the 50th percentile MC values are between 0.5 and 1 cent/esa.km
- Overall low values of marginal cost can be explained by the nature of WA pavements which are quite strong with relatively low deflection and a longer pavement life. In addition, treatment unit rates associated with the asset preservation strategies employed used by MRWA, including relatively low cost profile correction treatments, are quite low when compared with other Australian road authorities, resulting in overall low MC values.
- Comparing across WA regions, Great Southern has the highest overall MC values (distribution) while Mid-West Gascoyne has the lowest overall MC values (distribution). TMI may be a contributing factor explaining this trend. Great Southern region has the wettest TMI within all WA regions while Mid-West Gascoyne has the driest TMI values. Different unit rates used by regions also contributes to the variation of MC across the regions.
- Higher deflection ranges are associated with higher MC values. This is expected as deflection is directly related to the strength of the pavement and its load carrying capacity.
- A small proportion of the sections had zero (0) marginal cost values. When investigated it was observed that most of these sections have very low traffic with low proportions of heavy vehicles. Consequently, regardless of the increase in ESA loading levels, these sections triggered exactly the same treatments over the analysis period, yielding 0 (zero) marginal cost.

The average MC values for the asphalt network grouped by deflection ranges are presented in Table ii.

Table ii: Average MC values for regions grouped by deflection- asphalt network (cents/esa.km)

Deflection (micron)	Goldfields Esperance	Great Southern	Kimberley	Metropolitan	Mid-West Gascoyne	Pilbara	South West	Wheat belt
<500	0.51	0.44	0.12	0.45	0.57	0.41	0.76	0.89
500-1000	1.70	1.53	0.43	1.25	1.32	1.81	1.65	2.42
>1000	6.32	2.23			0.72	1.62	3.35	5.23

For the asphalt network, it was found that:

- MC distribution for the asphalt surfaced network ranges from 0-10 cents/km. For all regions, the 50th percentile MC values are less than 1 cent/esa.km
- Higher deflection ranges are generally associated with higher marginal cost.

Significance of the final setup

The various trials and adjustments applied in determining a final set of marginal cost values have led to a significant change in the MC estimates, with this illustrated by the data in Table ii with a halving or more of the original estimated values reported earlier in the study.

The reasons for the above, are as follows:

1. The treatment strategies used by MRWA, particularly where adequate structural capacity exists and the need is to replace and/or reprofile the road surface/upper pavement, means treatment costs are significantly lower than would be the case if a full rehabilitation is needed.
2. Accounting for a penalty cost where a treatment is delayed and accounting for asset consumption at the end of the analysis period increases the treatment cost, but the overall agency cost and therefore the MC is dominated by the MRWA treatment strategies.

Estimated benefits to heavy vehicle operators

Consideration of the benefits to heavy vehicle (HV) operators of a cost recovery process was investigated by computing the road user cost savings, both total savings and HV user specific savings, associated with a well-managed road network and corresponding road preservation funding with alternative funding levels. This involved determining the road user costs associated with different funding levels, and therefore different future road conditions. Funding levels investigated represented unlimited funding, i.e. the optimum level of funding to support target levels of service, and two lower funding levels, namely 80% and 60% of the unlimited funding.

Productivity benefits (PB_HV), representing road user cost savings for heavy vehicle operators, are reported as the benefit per HV.km (cents) and the benefit per HV esa.km (cents) relative to a constrained budget, defined for summary reporting as 60% of the unlimited budget. Net productivity benefits (NPB_HV) are reported as the PB_HV less the computed marginal cost of road wear, i.e. NPB_HV per esa.km = PB_HV per esa.km less MC per esa.km.

Two regions from the pilot-networks employed in the earlier stages of this study, representing two road segments in Great Southern and Kimberley, were employed for demonstration purposes, leading to the following outcomes:

a) For the Great Southern example, the marginal cost of road wear (2.6 cents per esa.km) was greater than the estimated productivity saving (1.7 cents per esa.km), resulting in a net productivity loss of approximately 0.8 cents per esa.km.
This example also had the following features reflecting the characteristics (including pavement history and condition, strength, climate, traffic, etc) of the case study road chosen, the LoS policy applied (CW), and the impact of these on road user costs and total transport costs:

- The marginal cost rate is high (approximately 90th percentile value for the region) with this most probably a consequence of the combination of the current condition, pavement strength, and legacy construction standards.
- Whereas the economic analysis demonstrates that the unlimited budget minimises total transport costs, and road user costs, the reduction in user costs is insufficient to offset the cost of preservation and renewal attributable to HV's.
- The average IRI values (20 years) are shown to vary from approximately 3.6 (Unlimited budget) to 4 (60% budget) which are well below the rehabilitation limit of 5.3 IRI for a CW road category, with the lower value delivering TTC savings and RUC savings.
- The unit cost rates in Great Southern are also relatively high, with this impacting marginal costs. The average road user cost per heavy vehicle is also relatively low, with total numbers also low. This combination results in less opportunity for net productivity benefits.

b) For Kimberley, the marginal cost of road wear (1.6 cents per esa.km) is slightly less than the estimated productivity saving (1.96 cents per esa.km), resulting in a net productivity benefit of 0.36 cents per esa.km.
The case study had the following features reflecting its particular characteristics and the impact of these on road user costs and total transport costs:
   - In this case the economic analysis demonstrates that the unlimited budget also minimises total transport costs, and road user costs, and delivers net HV-related road user cost savings per esa.km, albeit marginal savings.
   - This also reflects the LoS policy (BW) which is associated with a lower maximum roughness, with the achievement of this most likely influenced by the lower costs of major treatments being some 26% less than the Great Southern rates.
   - The average IRI values (20 years) are shown to vary from approximately 2.7 (Unlimited budget) to 3.4 (60% budget) which are well below the rehabilitation limit of 4.2 IRI for a BW road category, with the lower value delivering TTC savings and RUC savings.
   - A characteristic of this case study is the substantial variation in traffic levels, with these varying from around 200 AADT to over 4000 AADT. If considered separately, net benefits vary from a low of almost zero to approximately 1.3 cents per esa.km respectively, i.e. they increase with increasing road use.
   - A further characteristic of this case study is, the minimum TTC for the sections of road displaying different traffic levels (four in total) showed that two of these coincided with unlimited funding (approx. 620 and 4000 AADT) and two coincided with the 80 percent budget scenario (approx. 200 and 680 AADT). This illustrates a possible issue with the level of policy applied, i.e. it does not coincide with minimum transport costs for each individual segment, although it does for the road examined.

From the above, even considering the limited scope of the examples, it is clear that a number of factors impact marginal costs and potential productivity benefits, and include:

- The LoS policy which impacts road user costs, and if it can be achieved at a lower cost as determined by unit treatment costs and favourable road characteristics, then marginal costs will be lower and net benefits are likely to be higher.
- Underlying assumptions/factors including the road deterioration models employed, these being based on national studies with account taken of the observed relatively low rate of structural deterioration in Western Australia, and the life of surfacings, being significantly longer than national estimates.

Communications tool for investigating marginal costs

As a part of the project deliverables, an interactive communication tool incorporating the marginal cost outputs for MRWA road network (road segments with valid 2018 TSD condition data) has been prepared using Microsoft Power BI software. The tool provides the opportunity to review the marginal cost values at network, regional and road section level. It also provides the opportunity to review the changes in Marginal cost with the changes in different parameters such as road link category, traffic, deflection, rainfall, surface type, etc. as appropriate. The tool is aimed at asset management practitioners and those responsible for managing heavy vehicle access.

The values in the tool represent the modelling undertaken across the network as described in this report, and therefore are the best available estimates at this point in time, but further improvements are possible as research outcomes from the parallel study, WARRIP-Improved Decision Making (IDM), emerge.

Recommendations for application of the outcomes and further research

1. The results and outputs of the marginal cost component of this study should be communicated to asset managers and heavy vehicle access managers and applied in assessing risks to road pavement assets, and the likely cost impacts of heavy vehicle use.
2. Further research is warranted once the findings of the ongoing Improved Decision Making (IDM) project are available. This would provide a more confident basis for forward modelling of road performance and its corresponding impact on the level of agency costs, and therefore marginal costs, and road user costs and consequently productivity benefits.
3. A future study should also examine the impact of the current LoS policy and a minimum total transport cost based economic LoS, with this undertaken once improved road deterioration models are available from the IDM.

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TABLES

FIGURES

1 INTRODUCTION

1.1 PROJECT OBJECTIVE AND SCOPE

The objective of this project is to provide a defensible approach to managing the Western Australian (WA) arterial road network to agreed standards under unexpected or increasing heavy vehicle (HV) loads.

In order to be defensible, the approach must be based on proven tools, models and approaches relevant to road types and environments found in Western Australia. However, this does not preclude examining literature from elsewhere in Australia or internationally.

There is a broader issue of good communication with all relevant HV stakeholders regarding road management, regulation and HV charging in WA. The positive benefits of providing appropriate levels of service to HVs across WA needs to be communicated. There are significant economic benefits to HV road users and the community that exceed the charges and costs. These benefits are derived from a well-managed road network where road preservation funding is at an appropriate level and directed to where it is needed.

Good community communication can allay current perceptions that the State and Federal governments are not in touch with local communities, including industry and producers, and their needs.

1.2 BACKGROUND INFORMATION

The Main Roads Western Australia (MRWA) arterial road network is subject to significant increases in heavy vehicle loading in areas where mining and other major development works occur impacting on the performance of the road infrastructure. Concessional loading is also allowed in the transport of grain and other agricultural products.

In many instances these heavy vehicle load increases are either not planned or accounted for in the design and/or the ongoing asset management of these roads. Consequently, the road assets can be consumed much quicker than expected, requiring substantial re-investment and earlier interventions, which normal funding arrangements are not able to meet.

MRWA needs a sustainable and strongly defendable approach to managing its road network to meet its level of service obligations to road users. Some form of heavy vehicle costing process is needed to ensure impacts are fully understood spatially on the network, and possible cost recovery and/or an adequate source of fully hypothecated funding requires consideration that can be directed to where the re-investment is needed.

In the past MRWA has relied on ad hoc arrangements and various approaches to estimate heavy vehicle road use charges. These approaches can range from estimating the cost of consumption of the pavement's structural capacity in terms of cumulative equivalent standard axles for specific roads to estimating the marginal cost of road wear which basically covers the costs of periodic maintenance and rehabilitation to restore pavements to their expected levels of service. The marginal cost approach was developed with support from the National Transport Commission (NTC) and Austroads as an equitable means for determining the cost of road wear (Austroads 2012).

This project is aimed at applying the most viable and sustainable approach to heavy vehicle impact assessment and costing in the MRWA context based on a proven methodology.

A further aspect of this initiative that is relevant is the need to communicate the benefits, not just the costs, of such an approach. This is because any marginal increase in investment in asset preservation and renewal delivers a significant benefit to road users, i.e., the communication of both the associated costs and benefits is vital. The link to hypothecation is also vital, as it provides a possible funding mechanism and transparency which concerns users.

1.3 PROJECT CONTEXT

Communication

Communication is at the heart of this project, with the need for cost recovery being a contentious issue with users often seeing little transparency in its derivation and justification whilst other charges continue to be levied, i.e., registration and licencing and fuel excise. The benefits of a fair charging system have also not been explained, yet it is well known that optimal funding maximises savings to users, i.e., as productivity benefits. In simple terms, a positive marginal benefit cost ratio (MBCR) comparing the current base level of maintenance and funding and optimum investment can be used to demonstrate a benefit to users occurs. It is also well known that prevention is better than cure, and timely spending to maintain LOS under greater loading lowers costs to users. It is for this reason that communication should address both costs and benefits.

Another challenge when applied at a network wide level, is to ensure users benefit appropriately, where hypothecation needs to take place, that is, the recovered charges should be spent where the asset has been utilised. Traditionally, Federal and State Treasuries have objected to this, although views may be changing.

The case for development contributions from road users or developers who significantly increase the loading on a particular road, and therefore bring forward the need for investment, frequently occurs at a local government level in WA, but is not supported by any state-wide regulations or laws. It is in effect voluntary. However, in some other states this is regulated, such as in Queensland, where The Guide to Traffic Impact Assessment (QDTMR 2018a) requires proponents of development to ensure that increased traffic generated by development does not worsen the pavement condition of state-controlled roads (SCR). Impacts are determined by undertaking a Pavement Impact Assessment (PIA) as explained earlier. The lack of direction from legislation is a concern and is arguably a significant hurdle.

Whereas the functionality and type of communications tools to be developed are not clear at this stage, the need for communication is, therefore in the first instance using simple presentation tools informed by case studies to illustrate the principles of attributable costs and benefits to different target groups. These could be simple as conventional well illustrated presentations or include a simple tool which can manipulate results and show interactively the effects of certain changes. Tools such as MS PowerPoint and PowerBI are capable of aiding this task provided the required data/results are available. The latter tool also has the benefit that it can utilise GIS referenced information.

Heavy Vehicles

Currently in WA 36.5 m road trains have extensive access, with 53.5 m road trains having significant access (sometimes with operating conditions attached) outside the main urbanised regions of the state. Under the PBS Scheme in WA, Levels 3A and 4A are permitted on the main connecting highways and arterials of the state road network, permitting vehicles up to 42.5 m in overall length.

Industry is expected to have an ongoing demand for higher efficiency vehicles for the Agriculture and Mining sectors. This is anticipated to create safety issues on the current network when overtaking due to the length of time needed to overtake these long vehicles and the current length of overtaking lanes. The width of lanes can also be a safety issue for longer vehicles with increased tracking.

While these are issues that are related to the capacity of the road network under increasing access, rather than the marginal cost from increased loading of pavements, the two are linked. Merely recovering costs for roads that are experiencing accelerated deterioration due to vehicles that exceed the capacity they were designed for, without considering the need for increasing capacity, does not lead to a sustainable and high-performing road network. Therefore, the cost recovery approach elaborated in this project should be considered along with investment for increased network capacity when developing policy. Marginal costs can be applied considering improvements needs, however benefits would also be gained by other users and therefore appropriate consideration of how costs are shared would require consideration.

Pavement Deterioration

There are specific approaches needed in WA due to geology that is not found in other states as extensively as in WA. Whereas a significant proportion of pavement failure in other states may be due to failure of the subgrade or associated drainage impacts, this is rarely the cause of pavement failure in WA, which generally has well drained and stable subgrades providing relatively firm support for pavement bases.

While roughness can be used as a singular measure of pavement condition in other states, additional pavement condition indicators such as rutting and strength measurements are used in WA to efficiently identify and initiate appropriate maintenance intervention measures on deteriorating pavements.

For these reasons, modelling of pavement deterioration in this project needs to be specific to WA. ARRB's experience in projects such as modelling work completed on the Albany Highway provide us with the required understanding of WA's specific modelling requirements.

1.4 PRODUCTIVITY BENEFITS

In the context of this study, productivity benefits comprise savings in attributable road user costs (RUC), comprising the sum of heavy vehicle operating costs (VOC), travel time and cargo-related costs associated with alternative road asset management treatment strategies and associated levels of service, and funding levels. The total saving to industry equals the product of the number of trips and the cost saving per trip. However, reductions or increases in RUC can occur leading to differences in the level of benefits. This assumes that a net reduction from current funding levels will not occur.

Savings will arise primarily because of smoother and better maintained roads. These combine to reduce operating costs and allow typical journey speeds to be unaffected by road condition.

Models and parameter values for the determination of attributable road user costs exist with these available from the Australian Transport Assessment and Planning (ATAP) guidelines (Transport and Infrastructure Council 2015). The VOC component addresses both uninterrupted or free flow, and interrupted flow, with the former considered appropriate for this study where rural and interurban travel is assumed to be the focus for the work. The VOC models comprise a set of simple regression models that includes the above parameters as independent variables and was based on an analysis that produced estimates of unit vehicle operating costs over a wide range of road surface and alignment conditions for a range of typical traffic compositions. Estimated journey speeds are used in determining travel time and cargo-related costs. The guidelines include models for a 20-vehicle fleet, but other cases can and have been generated in other studies. Model variables include road and use characteristic parameters such as curvature, road rise and fall, vehicle speed and road roughness. Vehicle characteristics are represented in the fleet, and in defining vehicle loading in terms of Gross Vehicle Mass (GVM) with this also associated with the estimated number of ESAs for the vehicle configuration.

The relatively simple structure of the models means they can easily be used in various computational tools either as equations, or in the form of look up tables. The fact that they are nationally endorsed provides a degree of reassurance to users.

1.5 STRUCTURE OF THIS REPORT

Following the statement of the objective, scope, and background of the project mentioned earlier in this section, the subsequent sections of the report are as follows:

Section 2 documents the development and modification of the analysis tool and parameters developed through analysis of a Pilot network and a number of trails and illustrates the impact of the various analysis approaches investigated.

Section 3 provides an overview of the available MRWA network data that was used in the later analysis.

Section 4 details the analysis outputs of marginal cost calculations for the entire MRWA arterial network

Section 5 provides a description of the final conclusions and recommendations for MRWA.

Section 6 describes a communications tool that has been developed in PowerBI

Section 7 is the conclusion of the report containing a number of recommendations.

2 DEVELOPMENT AND MODIFICATION OF ANALYSIS TOOL AND PARAMETERS

2.1 SELECTION OF MODELLING TOOL

The determination of marginal cost required long term analysis of pavement performance (50 years for the current work) with provision for treatments in response to using various loading scenarios. So, the capabilities and functionalities of the available tool options (FAMLIT, PLCCDT, dTIMS) were considered in relation to the required outcomes of the project and dTIMS with some modifications was selected as the best tool for the analysis.

The main reasons for selecting dTIMS were:

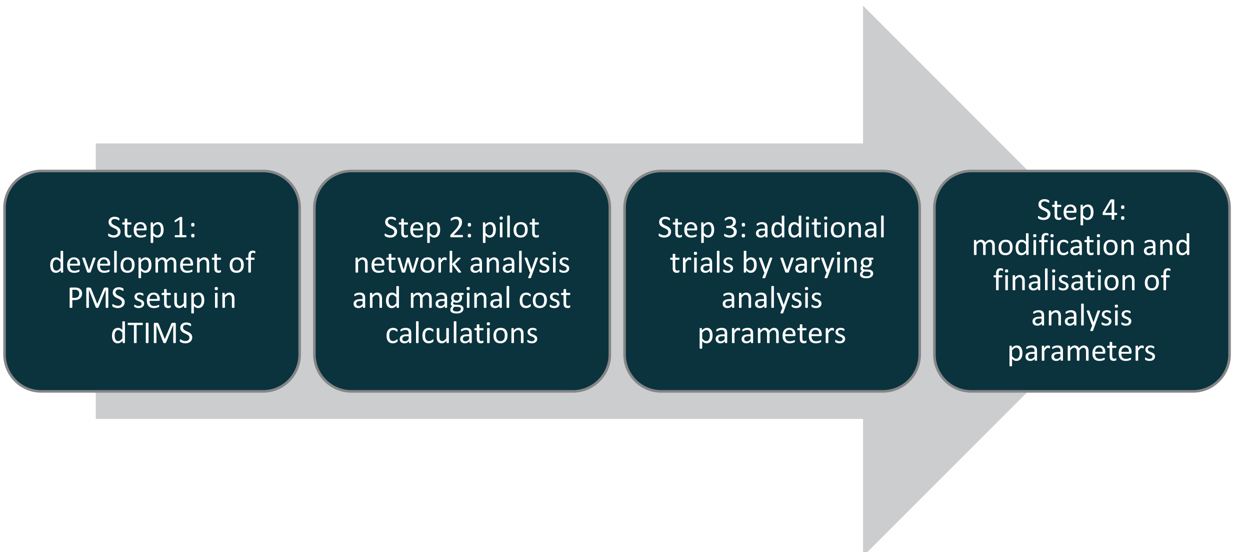
- dTIMS is capable of handling large datasets while analysing the long-term performance of pavements, in this case 50 years. This opens the possibility of running the full MRWA network for marginal cost analysis in future.
- dTIMS can analyse network condition for both unconstrained/ constrained budget scenarios
- All the desirable functionalities of the ARRB PLCC tool utilised under Austroads project AAM6143 can be coded into dTIMS and has been done as a part of this project.

The coding involved adapting models, changing modelling parameters, calibration etc. to keep it consistent with MRWA practices, e.g., seal life calculations and road condition and structural deterioration as per the MRWA pavement modelling document.

2.2 DEVELOPMENT OF THE ANALYSIS SETUP

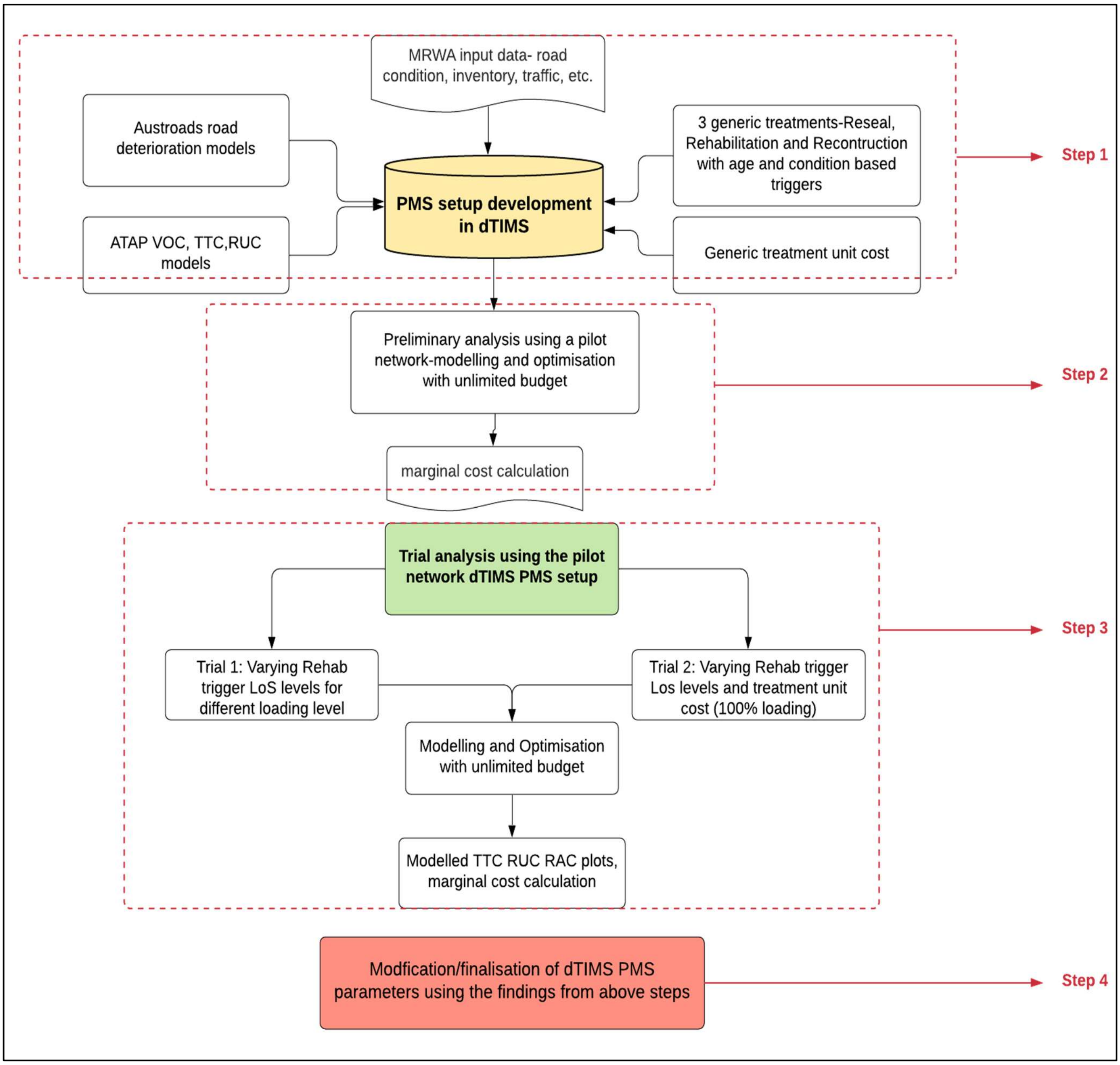
The development of the PMS analysis setup for this project had been a continual process where the initial setup in dTIMS was prepared at the beginning of the analysis through implementation of deterioration models, treatments, LOS, etc. However, over time, various parameters were modified based on the outputs of preliminary pilot network analysis and findings from different trialled approaches. The whole process can be broadly categorised into 4 steps as illustrated in Figure 2-1.

Figure 2-1 PMS setup development and modifications over time



The components involved in each step and their interactions are shown schematically in Figure 2-2. Each step is broadly outlined in the following sections.

Figure 2-2 Schematic representation showing steps in dTIMS setup development for analysis



2.2.1 STEP 1: DEVELOPMENT OF PMS SETUP IN DTIMS

Deterioration Models

The deterioration models and works effects models used in the dTIMS setup are as follows:

- Austroads Roughness Deterioration Model
- Austroads Rut Depth Deterioration Model
- Austroads Cracking Deterioration Model

All of these were calibrated for WA conditions, based on the findings of the AAM6143 *Prolonging the Life of Assets under Increasing Demand* project (Austroads 2021), with the following significant changes to the default models:

- a surfacing risk factor of 1.1, based on the Main Roads' seal risk model, with seal life estimated using the full oxidation model inputs
- a crack initiation factor 1 to ensure consistency with Main Roads' risk estimate
- a crack progression factor of 3, with this determined based on the reported pavement repair areas from Main Roads' MMIS for aged seals
- a structural model local calibration factor of 5, this signifying a minimal loss in SNC with time consistent with almost no change in measured deflections over an extended time-period
- application of Relative Performance Factors (RPFs) to accelerate rutting and roughness progression within the accelerated deterioration phase.

The modelling factors are shown in Figure 2-3 and the analysis switches are presented in Figure2-4.

Figure 2-3: Screen shot showing Network Level Modelling Factors from the dTIMS setup

Network Level Modelling Factor							
		Road Rank					
	Null	1	2	3	4	5	6
Null	-11111	-11111	-11111	-11111	-11111	-11111	-11111
NL_Calib_Rut_Krid	-11111	1	1	1	1	1	1
NL_Calib_Rut_Kr	-11111	1	1	1	1	1	1
Relative Compaction Value ((	-11111	100	100	100	100	100	100
NL_Calib_Crk_kcis	-11111	1	1	1	1	1	1
NL_Calib_Crk_kcia	-11111	1	1	1	1	1	1
Risk Factor	-11111	6	6	6	6	6	6
NL_Durability_test_D	-11111	10	10	10	10	10	10
Agg_Size	-11111	14	14	14	14	14	14
Asphalt Voids Percentage	-11111	5	5	5	5	5	5
NL_Calib_Crk_kcps	-11111	1	1	1	1	1	1
NL_Calib_Crk_kcpa	-11111	1	1	1	1	1	1
NL_Calib_IRI_Kiri	-11111	1	1	1	1	1	1
NL_FLTF	-11111	0.9	0.9	0.9	0.9	0.9	0.9
NL_Calib_SNCratio_Ks	-11111	5	5	5	5	5	5

Figure2-4: Screen shot showing modelling and treatment switches from the dTIMS setup

Control panel for various modelling/ treatment switches							
		Road Rank					
	Null	1	2	3	4	5	6
Null	-11111	-11111	-11111	-11111	-11111	-11111	-11111
Flag_VOC_use	1	1	1	1	1	1	1
c_Trt_Trig	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Flag_SC_MR	1	1	1	1	1	1	1
Flag_SNC_ratio	1	0	0	0	0	0	0
Flag_Reseal_SC_thick	20	20	20	20	20	20	20
Flag_Resurf_MR_Thick	40	40	40	40	40	40	40
Flag_Resurf_Thick	60	60	60	60	60	60	60
Flag_RPF_Use	1	1	1	1	1	1	1
Flag_Lane_Dir_Factor	1	1	1	1	1	1	1
Flag_ESA_Std	1	1	1	1	1	1	1
Flag_ESA_Higher	-11111	-11111	-11111	-11111	-11111	-11111	-11111

Estimated seal lives and maximum asphalt lives (used in the crack initiation model) were based on the MRWA modelling document as shown in Table 2-1 and Table 2-2.

Table 2-1: Expected seal lives for WA regions

Region	Predicted Av. Life Size 10	Predicted Av. Life Size 14
Goldfields-Esperance	17.2	18.0
Great Southern	15.3	18.4
Kimberley	14.2	15.1
Metro	16.9	18.9
Mid West - Gascoyne	16.7	17.2
Pilbara	14.1	15.0
South West	16.6	19.1
Wheatbelt	16.0	18.1

Table 2-2 Maximum asphalt life by surface material type

Asphalt surface material	Maximum asphalt Life
DGA	21
IMA	17
OGA	15
OGA on DGA	15
SMA	21

Additional models included in the dTIMS setup development during Step 1 were:

- ATAP Road user cost (RUC) model including vehicle operating cost (VOC) and travel time cost.
- Structural model with calibration factor to suit WA conditions. Calculation of modified structural number (SNCi) was based on the following.

  - Calculation of in-service structural number at the beginning of the analysis based on input deflection data

Equation 1

$$\mathrm{SNCi} = 3.2 * ((\mathrm{D0} * 1.2/1000.0)\char`^(-0.63))$$

  - Calculation of SNC ratio at the beginning of the analysis and in the future years using structural age, design life and TMI (with necessary calibration)

Equation 2

$$SNCratio = (2.0 - EXP((1.0/Calib\_Ks) * Age\_Struct * ((0.2518/Design\_Life\_Struct) + 0.00004413 * TMI)))$$

  - Estimation of pavement structural strength at the time of construction using SNCi and SNC ratio

Equation 3

$$SNC0 = SNCi/SNC\ ratio$$

  - Modelled annual SNCi values for the future years using SNC0 and SNCratio

Equation 4

$$SNCi = SNC0 * SNCratio$$

However, based on the preliminary analysis outcomes, structural number calculation method was modified in Step 4 before full network analysis.

Treatments and Triggers

During initial dTIMS setup development, three generic treatments were coded in dTIMS:

- Reseal / Resurface (with 2 additional variants, Shape Correction and Mill & Replace)
- Rehabilitation
- Reconstruction

Figure 2-5 shows a screenshot of the treatment triggers which were implemented in dTIMS during Step 1. The classes AW, BW and CW correspond to different MRWA road link categories.

Figure 2-5: Treatment triggers for Climatic Regions used in the analysis

	AW	BW	CW
Intervention Triggers - Time Based			
Minimum **Resurface** Interval	16	16	16
Maximum **Resurface** Interval	22	22	22
Minimum **Rehabilitation** Interval	2	2	2
Maximum **Rehabilitation** Interval	100	100	100
Minimum **Reconstruction** Interval	2	2	2
Maximum **Reconstruction** Interval	150	150	150
Intervention Triggers - Condition Based			
Rehabilitation IRI Trigger	3.8	4.2	5.3
Reconstruction IRI Trigger	4.8	5.2	6.3
Rehabilitation Rutting Trigger	10	10	10
Reconstruction Rutting Trigger	15	15	15
Resurface Cracking Trigger	5	5	5
Rehabilitation Cracking Trigger	10	10	10
Reconstruction Cracking Trigger	20	20	20

The treatment costs for link categories are shown in Figure 2-6.

Figure 2-6: Treatment costs (Step1)

Null	0
Reseal	6
Reseal_SC	20
Resurf	40
Resurf_MR	60
Rehab_SS	80
Rehab_AC	110
Recon_SS	120
Recon_AC	150

Based on the preliminary analysis outcome, all treatments and associated unit rates were modified in Step 4 before full network analysis.

Analysis set-up and processing of results

The analysis set-up developed in Step 1 used the following rules and models:

- Adoption of time and condition-based intervention limits for surface age, cracking, rut depth and roughness according to a hierarchy by road class, and a maximum loss in SNC ratio from the last date of pavement rehabilitation or reconstruction.
- Austroads 12-Class Vehicle Counts and ATAP (Transport and Infrastructure Council 2015) ESA factors per heavy vehicle.
- The data employed was supplied by Main Roads and included a full set of road network data as specified for the IDM2 project, and traffic data.
- Various analysis runs were undertaken per analysis segment, with these varied to representing five loading scenarios, namely 100% loading based on current (and projected) traffic, -40%, -20%, +20% and +40%. This approach was employed to allow generation of a marginal cost (MC) rate per analysis segment.

ESA values for various vehicle class for various loading scenarios are shown in Table 2-3.

Table 2-3 ESA values for loading scenarios used in the analysis

Austroads vehicle class	ESA loading level				
	(100-40)%	(100-20)%	100%	(100+20)%	(100+40)%
Class 1	0.001	0.001	0.001	0.001	0.001
Class 2	0.006	0.007	0.008	0.009	0.011
Class 3	0.005	0.008	0.012	0.018	0.026
Class 4	1.094	1.616	2.318	3.238	4.421
Class 5	2.746	4.580	7.581	12.195	18.948
Class 6	1.261	2.197	3.588	5.564	8.274
Class 7	1.929	3.133	5.071	8.019	12.295
Class 8	2.079	3.447	5.655	9.017	13.897
Class 9	1.975	3.142	4.969	7.686	11.563
Class 10	2.400	3.944	6.349	9.909	14.958
Class 11	3.197	5.274	8.416	12.950	19.252
Class 12	4.245	7.261	11.863	18.547	27.873

2.2.2 STEP 2- PILOT NETWORK ANALYSIS

Selection of Road Segments

The pilot network was determined by a desire to include road segments that were subject to a range of rainfall and pavement strengths (deflection), since these are both considered as having an impact on marginal costs; and ensuring the road segments were part of contiguous road segments within their region. It was decided to take road segments from three administrative regions to limit numbers while providing a range of climates. The consideration of pavement strength in the selection process involved obtaining contiguous road segments with low (< 500 μm), moderate (500 – 1000 μm) and high (>1000 μm) D_0 deflection values as shown below:

- Kimberley – Moderate to high deflections
- Goldfields-Esperance – Low to moderate deflections
- Great Southern – Moderate deflections

As a result of the review of the data, a total of 3,002 sealed road segments were selected for the preliminary analysis. Table 2-4 summarises the selected section details along with the distribution of pavement strength across the three regions. Table 2-5 outlines the underlying climate conditions of the selected road sections.

Table 2-4: Selected road sections for preliminary analysis with strength information

Region	Road (direction)	No. of segments	Total length of road segments (km)		
			D_0 <500	D_0 = 500-1000	D_0 >1000
Goldfields-Esperance	H005_S	1,877	133.3	46.9	7.4
Great Southern	M014_S	253	9.4	14.1	1.8
Kimberley	H011_S	872	8.6	65.6	13.0

Table 2-5: Selected Regions with Climate information used for the preliminary analysis

Region	Road Class	Typical TMI	Typical Rainfall (mm)
Goldfields-Esperance	AW	-29	200 - 500
Great Southern	CW	20	800 - 1200
Kimberley	BW	-10	500 - 800

Preliminary Findings

dTIMS setup prepared in Step 1 was used to analyse the performance of selected road sections over a 50-year period for unconstrained budgets. Marginal cost values were generated through queries applied to the dTIMS outputs which were subsequently processed within MS Excel to produce the final values. A selection of tabular presentations has been produced which illustrate the range of MC values against attributes such as geographical location, and the corresponding ranges of maximum deflection and rainfall (Table 2-6)

Table 2-6: Average marginal cost rates by deflection and rainfall range (cents/ESA.km)

Maximum deflection range (micron)	Rainfall range (mm)		
	200-500	500-800	800-1200
<500	1.15	2.41	0.99
500-1000	1.82	4.47	4.66
>1000	1.15	8.09	7.68

What is evident is the MC values vary in magnitude with a logical increase coinciding with high rainfall and high deflection, and corresponding lower values in drier and low deflection conditions, although the pattern is not fully consistent. Further exploration of this to include a range of traffic levels and other risk factors was warranted and was progressed in the next stage of the project by analysing the full network.

2.2.3 STEP 3 - TRIAL ANALYSIS APPROACHES

Marginal cost values from the pilot network analysis were generally lower across the network than anticipated. So, prior to analysing the full network, a few trial analyses were done using the pilot network to check the appropriateness of the LOS definitions across various link categories as applied in the dTIMS. The objective was to examine how changing the LOS definitions change the total transport cost (TTC), Road User Cost (RUC), and Road Agency Cost (RAC) as well as where the minimum TTC lies for various link categories. In addition, the effect of different treatment unit rates on TTC values was evaluated

Trial 1 - Varying LOS and loading level

In addition to the standard LOS, the pilot network was analysed for three LOS levels by varying the roughness trigger for rehabilitation treatments. The scenarios and corresponding roughness values for various link categories are presented in Table 2-7.

Table 2-7: Different LOS levels and corresponding rehabilitation roughness intervention values

Scenario	Link Category	Rehab IRI Level
Std_LOS	AW	3.8
Std_LOS+0.4	AW	4.2
Std_LOS+0.8	AW	4.6
Std_LOS-0.4	AW	3.28
Std_LOS	BW	4.2
Std_LOS+0.4	BW	4.6
Std_LOS+0.8	BW	5
Std_LOS-0.4	BW	3.52
Std_LOS	CW	5.3
Std_LOS+0.4	CW	5.7
Std_LOS+0.8	CW	6.1
Std_LOS-0.4	CW	4.18

Separate dTIMS analyses were done for the above LOS levels and five loading levels (60%, 80%, 100%, 120%, and 140%). Observations from Trial 1 are as follows:

- RUC decreases for all traffic levels as the LOS scenario moves towards a lower roughness IRI intervention level. The reason is intervening at a lower IRI level reduces the overall road user cost by improving the ride quality.
- RAC increases for all traffic levels as the LOS scenario moves towards lower roughness IRI intervention level. The reason is because treatments happen more frequently at a lower IRI rehab level.
- Marginal cost values display an increasing trend as the LOS scenario moves towards a lower IRI interventional level, as expected. Higher deflection is also associated with higher marginal cost.

Trial 2 - Varying LOS and Treatment unit cost (100% loading)

In Trial 2, in addition to the LOS scenarios in Trial 1, the unit cost of the rehabilitation and reconstruction treatments were varied. Four different treatment cost levels (25%, 50%, 75% and current 100%) were applied in the trial analysis pilot network. It was found that with the reduction in treatment unit rates, the lowest TTC moves towards lower IRI intervention levels caused by the reduction in both RUC and RAC.

Though the above trials gave some insight about the variation of TTC and marginal cost with the change in IRI intervention levels, no definite conclusion could be made on the appropriateness of LOS used in the pilot network analysis. This is most likely due to the small network size as well as the number of the LOS levels tested. Discussion with MRWA revealed that the treatment unit costs used by MRWA are also quite different (almost half) to those applied (100% cost) during the pilot network analysis. Considering the above, further modifications were made to the pilot network dTIMS setup to align it better with the current practices of MRWA.

2.2.4 STEP 4- REVISED PMS SETUP PARAMETERS

Significant changes were made in the dTIMS PMS setup prepared in Step 1 before analysing the full network. Treatment, triggers, and unit rates were adjusted to reflect the current practice of MRWA. The final dTIMS PMS setup and analysis approach incorporated the following parameters:

- LOS definitions as per MRWA modelling document which vary by link category
- Treatments and triggers with treatments based on MRWA modelling document and vary by surface type
- Treatment unit rates as supplied by MRWA – vary by regions
- Austroads road deterioration models

- Implementation of MRWA deflection and curvature models based on the MRWA modelling document
- Modelling annual structural number based on the modelled annual deflection values
- Incorporation of asset consumption costs in the marginal cost calculation to account for the percentage of the rehabilitation value consumed at the end of the analysis period
- A penalty cost calculation to cater for roughness values above trigger levels at the time of treatment application.

MRWA treatments in dTIMS

Treatments from the MRWA modelling document implemented in the dTIMS PMS setup are outlined in Table 2-8. Treatments vary by surface type and were applied accordingly. Corresponding treatment unit rates are presented in Table 2-9.

Table 2-8 MRWA treatments implemented in dTIMS PMS

Name	Description	Surface applied
CS	Sprayed seal	Sealed
GrOL	Rehab of CS	Sealed
RipSeal	Rip surfaces, add 50 mm gravel top up, reseal	Sealed
Slurry	A porridge of sand, stone and bitumen emulsion	Sealed
OGA2	Resurfacing applicable to specific surface type	Asphalt
ASDG_ASIM	Resurfacing applicable to specific surface type	Asphalt
ASOG	Resurfacing applicable to specific surface type	Asphalt
ASRH	Asphalt Rehab	Asphalt
SMA	Resurfacing applicable to specific surface type	Asphalt

Current analysis was based on an unconstrained budget; hence the holding reseal treatment (HCS) was not implemented.

Table 2-9 MRWA treatment unit rates ($/m^2)

Treatment	Great Southern	South West	Mid West Gascoyne	Goldfields Esperance	Kimberley	Metropolitan	Wheatbelt	Pilbara
RipSeal	42.99	36.52	34.23	43.43	34.12	58.00	44.39	47.38
GrOL	63.00	53.52	55.00	63.65	50.00	85.00	65.05	69.44
CS	3.58	4.20	4.00	4.10	4.20	9.00	3.80	3.20
Slurry	11.64	9.77	11.16	11.64	11.64	14.00	11.16	11.64
OGA2	65.10	65.10	65.10	65.10	65.10	65.10	65.10	65.10
ASRH	119.10	99.21	119.10	119.10	119.10	120.00	138.10	119.10
SMA	45.00	54.84	58.84	55.00	49.44	31.60	58.84	49.44
ASDG	45.00	54.84	58.84	55.00	49.44	39.00	58.84	49.44
ASOG	45.00	37.33	58.84	55.00	49.44	35.00	58.84	49.44
ASIM	45.00	54.84	58.84	55.00	49.44	53.00	58.84	49.44

Table 2-10 provides a comparison of various analysis parameters in the PMS setup developed in Step 1 for the pilot network analysis and the revised PMS setup used in the full network analysis

Table 2-10 Comparison of analysis parameters- Pilot network analysis and Full network analysis

Analysis Parameter	**Pilot Network PMS setup/ analysis**	**Revised Full network PMS setup/ analysis**
Deterioration model	Austroads road deterioration models	Same as Pilot network

Analysis Parameter	Pilot Network PMS setup/ analysis	Revised Full network PMS setup/ analysis
VOC, RUC, TTC models	Based on ATAP	Same as Pilot network
Network level modelling. factors	Assigned based on WA conditions	Same as Pilot network
Estimated Seal life/ Asphalt life	MRWA modelling document	Same as Pilot network
Analysis period & budget	50 year, unlimited	Same as Pilot network
Deflection and curvature models	Was not modelled directly (see structural number)	Modelled using MRWA modelling document
Structural number	Calculated from deflection at the beginning of the analysis. Future year values were based on SNC ratio	Calculated from deflection (initial and modelled values) over the analysis period.
ESA loading levels	5 levels at 20 % interval (-40% to +40%)	3 levels at 40 % interval (-40% to +40%)
Treatment cost	Generic treatment cost based on industry standards	Treatment cost and scope specified by MRWA
Minimum treatment Interval	10 years	Same as Pilot network
Asset consumption cost	Not Included	Included
Penalty cost	Not included	Included

Strength (Structural number) calculation

Calculation of modified structural number (SNCi) in the final PMS setup was based on the following

- Calculation of annual deflection D0 values based on MRWA modelling equation
- Calculation of in-service annual structural number based on the input deflection data (beginning of the analysis) and modelled deflection values (future years) using the following equation

Equation 5

$$\mathrm{SNCi} = 3.2 * ((\mathrm{D0} * 1.2/1000.0)\hat{}(-0.63))$$

- Calculation of SNC ratio at the beginning of the analysis and in the future years using structural age, design life and TMI (with necessary calibration)

Equation 6

$$SNCratio = (2.0 - EXP((1.0/Calib\_Ks) * Age\_Struct * ((0.2518/Design\_Life\_Struct) + 0.00004413 * TMI)))$$

- Calculation of pavement structural strength at the time of construction using SNCi and SNCratio

Equation 7

$$SNC0 = SNCi/SNC\ ratio$$

The process flowchart showing the interaction between various analysis parameters in the final PMS setup is also included in

Figure 2-7.

Figure 2-7: Analysis flowchart showing the interaction between parameters within the full network analysis

As displayed in the flowchart, the analysis steps can be broadly classified into two categories.

Process within dTIMS:

- Incorporation of Input data
- Implementation of models, LOS definitions, treatment trigger and reset expressions
- Modelling performance of various parameters for 50 years for various ESA loading levels
- Strategy generation (chain of treatments over the analysis period)
- Optimised strategy selection using an unconstrained funding level.

Process outside dTIMS:

Using the extracted output from dTIMS

- Desktop analysis to track the rate of progression over time
- Plotting and reporting TTC, RUC, RAC, etc. over time

- Calculation of additional costs- Asset consumption cost, Penalty cost, etc.
- Calculation and reporting of marginal cost.

2.3 FURTHER ANALYSIS USING DTIMS OUTPUTS

2.3.1 INCLUSION OF ASSET CONSUMPTION COST AND PENALTY COST

Asset consumption cost:

Asset consumption cost is a parameter ($ value) used to account for the percentage of the rehabilitation value consumed at the end of the analysis period accounting for the time since the last treatment was applied. This was considered relevant due to the long lives of pavements in WA therefore a significant proportion of a pavement's life may exist. In such circumstances it is reasonable that road users are not penalised by the full cost since they do not derive a benefit. Using the extracted outputs from dTIMS, the additional cost was added in the last year of analysis to account for the proportion of the rehabilitation/ resurfacing value (in terms of roughness IRI) consumed at the end of the analysis period (see Figure 2-8). All analysed sections received a dummy treatment based on the last major treatment applied. The formula used for asset consumption calculation is:

Equation 8

$$\begin{aligned}\boldsymbol{Asset\ consumption} &= [(\boldsymbol{Current\ IRI} - \boldsymbol{Reset\ IRI})/(\boldsymbol{Trigger\ IRI} - \boldsymbol{Reset\ IRI})] \\ &* \boldsymbol{Cost\ of\ the\ last\ major\ treatment}\end{aligned}$$

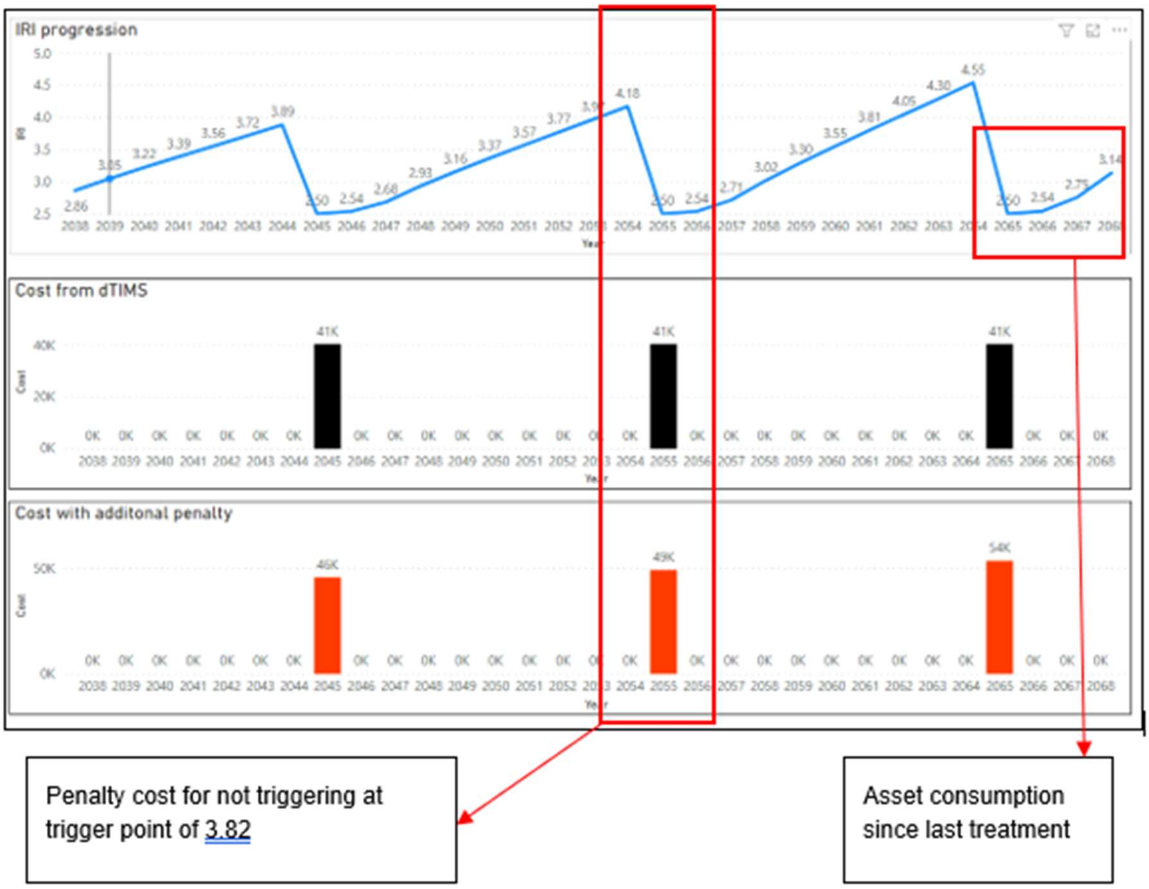
Penalty cost

Current analysis applied a minimum treatment interval year of 10 years between successive treatments to avoid generation of excessive treatment strategies. For some analysed sections, this rule caused the roughness (IRI) to exceed the trigger point before a treatment was applied. To account for this increase in roughness above the trigger point, an additional penalty was applied on top of the dTIMS generated treatment cost. A sample comparison between dTIMS generated treatment cost and the cost with the additional penalty is presented in Figure 2-8. The formula used for treatment cost with additional penalty is:

Equation 9

$$\begin{aligned}\boldsymbol{Treatment\ cost\ with\ penalty} &= [(\boldsymbol{IRI\ at\ the\ time\ of\ treatment\ application})/(\boldsymbol{Trigger\ IRI})] \\ &* \boldsymbol{standard\ cost\ of\ the\ treatment}\end{aligned}$$

Figure 2-8: Illustration of Asset consumption cost and penalty cost



2.3.2 MARGINAL COST CALCULATION

The process for generating the marginal cost from the full network analysis results (50-year life cycle analysis) was as follows:

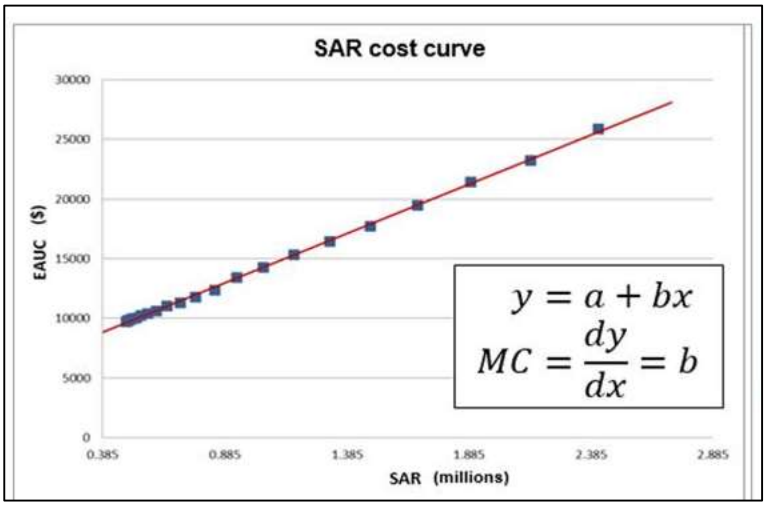
1. Extract the year-by-year road agency cost (RAC) stream for each segment
2. Add asset consumption cost to the final year RAC and add the penalty cost at the timing of the delayed treatment
3. Derive a discounted present value cost (PV_RAC) for the full analysis period.
4. Compute the equivalent annual uniform cost (EAUC) where EAUC discount rate=7%

Equation 10

$$\boldsymbol{EAUC} = (\boldsymbol{PV\_RAC} * \boldsymbol{DiscountRate})/(\mathbf{1} - (\mathbf{1}/((\mathbf{1} + \boldsymbol{DiscountRate})^\wedge \boldsymbol{Analysis\ period})))$$

5. Extract the annual number of equivalent standard axles (MESA) for each segment and derive a discounted MESA (PV_MESA) for the full analysis period
6. Convert PV_MESA to EAUC_MESA using the same formula as cost calculation
7. Create a linear regression of EAUC_RAC vs. EAUC_MESA from the results of the three loading scenarios for each segment, as per Figure 2-9, with the gradient*100 equal to the MC (in cents per ESA.km).

Figure 2-9: Relationship between EAUC and ESA/SAR



3 OVERVIEW OF MRWA ROAD NETWORK DATA

3.1 BACKGROUND

The road network data used in this analysis is the MRWA network supplied as part of the WARRIP IDM2 project with additional traffic data. This network contains over 180,000 one-hundred-metre segments. However, not all road segments have the surface condition and deflection data collected. Considering the availability of all condition data required for analysis, there is around 15,800 km of valid road length distributed over eight MRWA regions.

Because of the size of the network, the intention was to analyse each region separately and then aggregate the results. Prior to modelling, some initial exploratory analysis of the network data was done. This is briefly outlined in the following section.

3.2 EXPLORATORY ANALYSIS OF NETWORK PARAMETERS

3.2.1 NETWORK LOCATION AND LENGTH

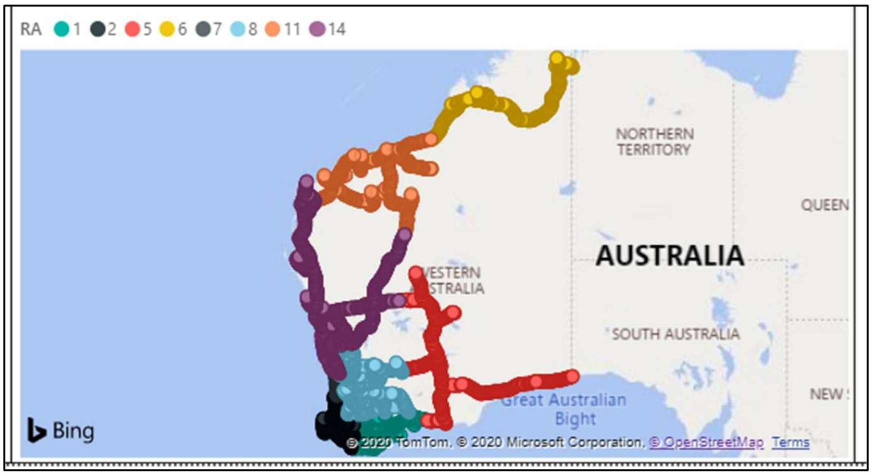
Table 3-1 presents the length of road sections in different MRWA regions. More than 90% of the road lengths on each subnetwork consist of sealed surfaces except Metropolitan region where around 70% of the road length is asphalt-surfaced and rest are sealed.

Table 3-1: Length of road sections by surface type in different MRWA regions

Region No (RA)	Region Name	Length (km) Asphalt	Length (km) Sprayed Seal	Total Length (km)
1	Great Southern	9.29	1528.62	1537.91
2	South West	63.05	1545.14	1608.19
5	Goldfields Esperance	23.75	2145.11	2168.86
6	Kimberley	2.28	1516.18	1518.46
7	Metropolitan	752.6	305.87	1058.47
8	Wheatbelt	37.79	2669.77	2707.56
11	Pilbara	10.88	2482.29	2493.17
14	Mid-West Gascoyne	24.42	3604.67	3629.09

Figure 3-1 also displays the location of road sections across MRWA regions.

Figure 3-1: Location of road sections on different MRWA regions



Level of service (LOS) definitions and treatment triggers defined in the dTIMS setup vary by MRWA road link category. Hence, the length of the road sections grouped by link category is also summarised in Table 3-2. More than half of the network length sit in either the "BW", "BW+" or "CW" category. It should be noted that MI/ MFF are the highest-ranked link categories and DW is the lowest in terms of LOS definitions.

Table 3-2: Length of road sections by MRWA Link category

	Link Category	Length (km)
MFF	Freeway	765.8
MI	Multilane road	731.36
AW	High standard single carriageway road	2208.42
AW+	High+ standard single carriageway road	1353.7
BW	Medium standard single carriageway road	5854.33
BW+	Medium+ standard single carriageway road	3050.84
CW	Basic standard single carriageway road	3364.68
DW	Unsealed or part sealed formed road	32.6

3.2.2 DISTRIBUTION OF LENGTH FOR VARIOUS PARAMETERS

The distribution of length in various traffic, rainfall, deflection ranges for all regions have been plotted in Figure 3-2.

Figure 3-2: Distribution of length by region within various traffic, rainfall, deflection ranges

The following observations are made from Figure 3-2:

- **Traffic**: The majority of roads in most regions have traffic below 10,000 AADT. Metropolitan and South West region have some lengths with AADT between 10,000-30,000. The Metropolitan region also has a small amount of road length with AADT more than 30,000.
- **Rainfall**: The majority of the regions have all the road lengths within annual rainfall ranges of 200-800 mm. Metropolitan and South West region have substantial road lengths with 800-1200 mm of annual rainfall
- **Deflection**: All regions have almost all lengths with low (<500 microns) to moderate (<1000 microns) mean deflection (Do max/1.3). However, very small proportions of road length in all regions display high mean deflection (>1000 microns).

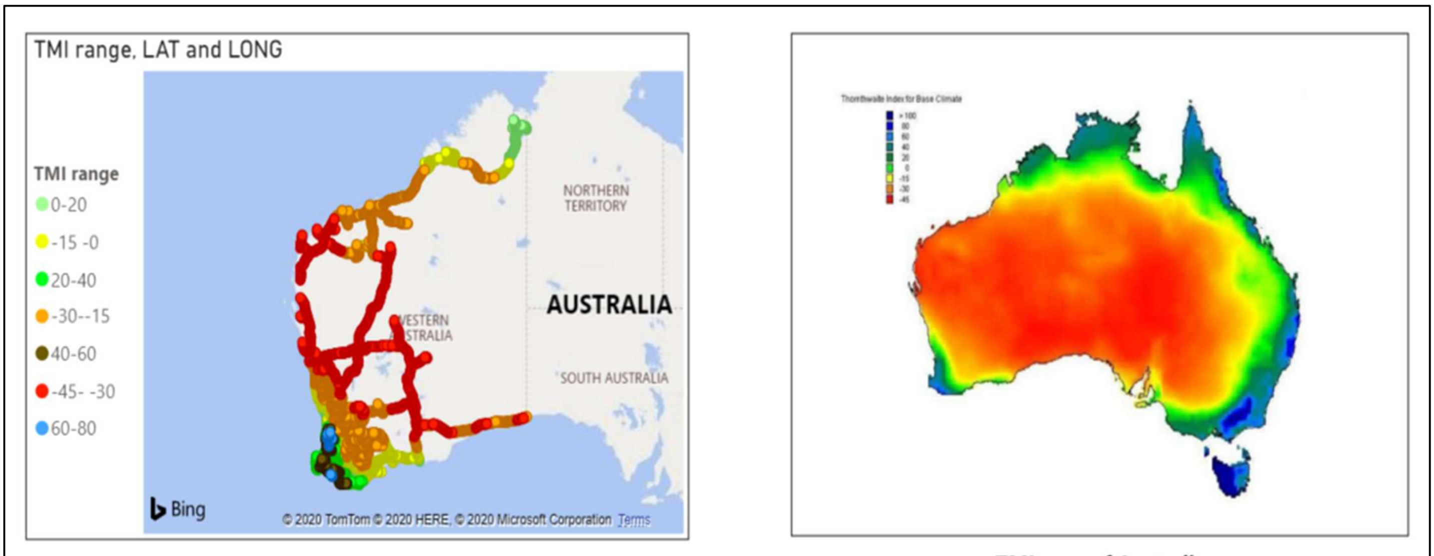
3.3 FILLING OUT MISSING INFORMATION – THORTHWAITE MOISTURE INDEX

Thornthwaite Moisture Index (TMI) is an important parameter applied in various places within Austroads deterioration models adopted for the current analysis. TMI was not readily available from the MRWA road database and hence was calculated for the whole network at 1 km interval using a Climate Tool developed as a part of an earlier Austroads research project (Austroads 2010c). Calculation of TMI involved the following steps:

- Creation of 1 km continuous section from ten 100-m segments
- Assigning the start latitude-longitude information for each 1 km section
- Estimating TMI for each 1 km section from the climate tool using the location information
- Assigning the TMI information to each corresponding 100 m segments

The resulting TMI map for the whole road network of MRWA has been plotted and compared against the TMI map of Australia from the Austroads work, see Figure 3-3, which shows that the estimated TMI aligns very well with the TMI map of Australia.

Figure 3-3: Estimated TMI map for MRWA road network and comparison with Australian TMI map



TMI calculated for each 1 km continuous sections using climate tool

TMI map of Australia

3.4 ANALYSIS FEATURES

To efficiently run the analysis within dTIMS, the following measures were taken:

- Due to the size of the network causing run time constraints in dTIMS, separate analysis was done for each region by surface types totalling 9 combinations (8 with region and sealed surface combinations and 1 for all asphalt surfaces within the network).
- For each of these combinations, three analysis runs were undertaken representing three loading scenarios, namely 100%, -40%, and +40% ESA loading based on current (and projected) traffic
- To avoid generation of excessive amounts of treatments and strategies over the analysis period, a 10-year minimum treatment interval period was applied between successive treatments.
- A 50-year analysis period was used to adequately capture the benefit from structural treatments.
- An unconstrained funding level was also applied during optimization.

4 ANALYSIS OUTPUT – MARGINAL COST

4.1 GENERAL

Separate analysis was done for each region by surface type. Outputs from the marginal cost calculation are presented separately for the sprayed sealed and the asphalt surfaced networks in the following sections.

4.2 MARGINAL COST- SPRAYED SEAL NETWORK

More than 90% of the road lengths in MRWA regions consist of sprayed seal surfaces, except for Metropolitan region where around 70% of the road length is asphalt surfaced and rest are sealed. Distributions of MC for sealed surfaces for all regions are shown in Figure 4-1. Average MC values grouped by deflection ranges are also presented in Table 4-1.

Figure 4-1: Marginal cost distribution by region for sealed surface pavements (cents/esa.km)

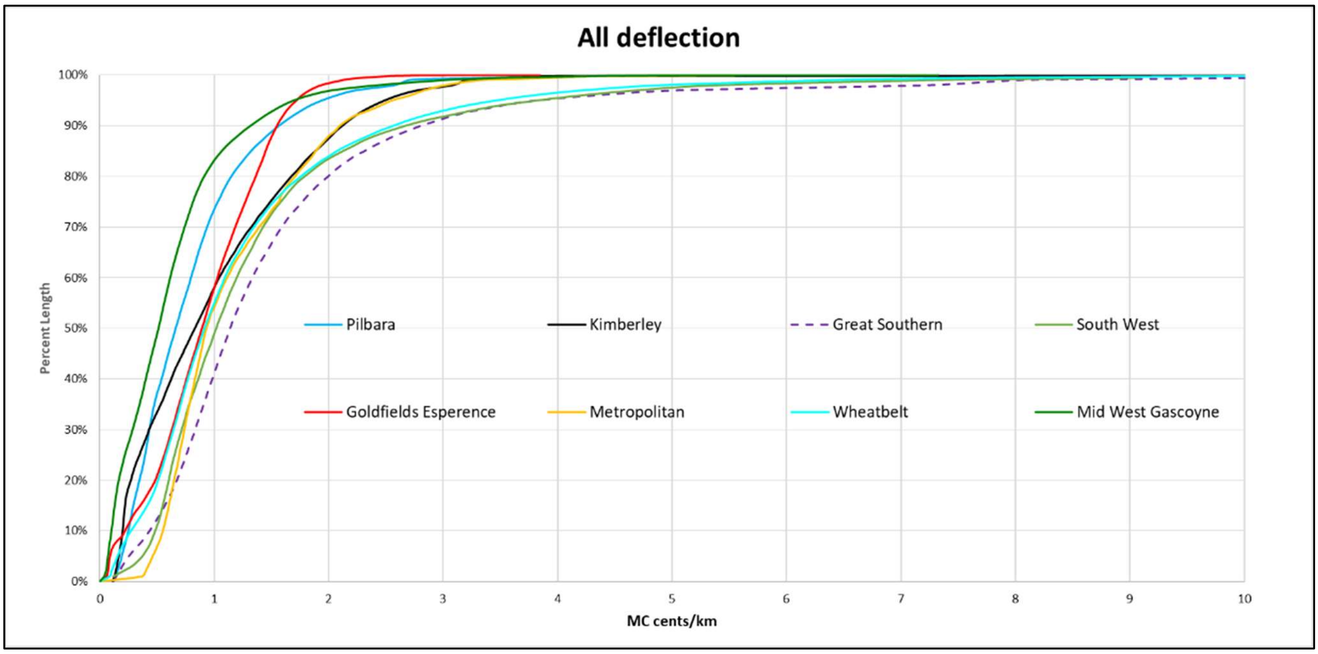


Table 4-1 Average MC values for regions grouped by deflection-sealed surface (cents/esa.km)

Deflection	Goldfields Esperance	Great Southern	Kimberley	Metropolitan	Mid-West Gascoyne	Pilbara	South West	Wheatbelt
<500	0.60	0.94	0.47	1.16	0.44	0.58	1.02	0.82
500-1000	1.26	2.30	1.47	1.73	1.33	1.29	2.34	2.20
>1000	1.44	3.96	2.27	5.40	2.43	2.16	5.27	5.15

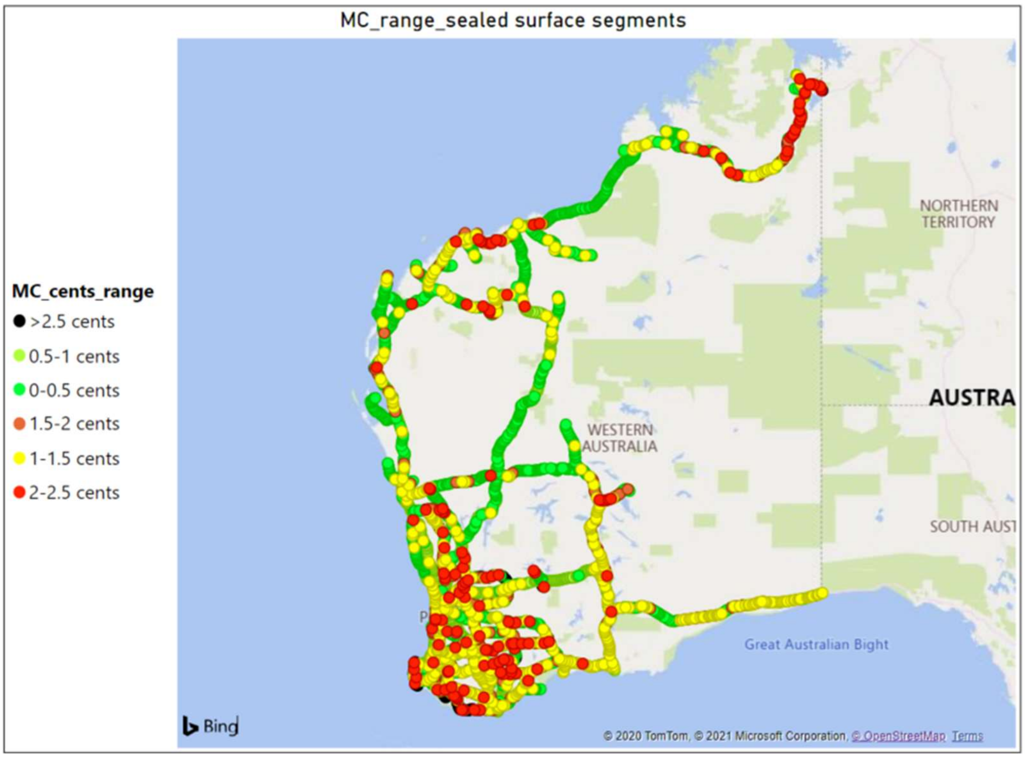
Observations from Figure 4-1 and Table 4-1 are as follows:

- The MC distribution for the sealed network ranges from 0-10 cents/km. For all regions, the 50th percentile MC values are between 0.5 and 1 cent/esa.km
- Overall low values of marginal cost can be explained by the nature of WA pavements which are quite strong with relatively low deflection and a longer pavement life. In addition, treatment unit rates used by MRWA are quite low when compared with other Australian road authorities, reflecting the

preventative strategies employed including profile correction with limited structural work, resulting in overall low MC values.
- Comparing across WA regions, Great Southern has the highest overall MC values (distribution) while Mid-West Gascoyne has the lowest overall MC values (distribution). TMI may be a contributing factor explaining this trend. Great Southern region has the wettest TMI within all WA regions while Mid-West Gascoyne has the driest TMI values (see Figure 3-3). Different unit rates used by regions also contributes to the variation of MC across the regions.
- Higher deflection ranges are associated with higher MC values. This is expected as deflection is directly related to the strength of the pavement and its load carrying capacity.
- A small proportion of the sections had zero (0) marginal cost values. When investigated it was observed that most of these sections have very low traffic with low proportions of heavy vehicles. Consequently, regardless of the increase in ESA loading levels, these sections triggered exactly the same treatments over the analysis period, yielding 0 (zero) marginal cost.

Mapping of marginal cost ranges for each 100-metre segments on the MRWA road network (sprayed seal surface) is presented in Figure 4-2 showing variations across the MRWA network.

Figure 4-2: Mapping of Marginal cost ranges on MRWA road network-sprayed seal surfaced segments



4.3 MARGINAL COST- ASPHALT NETWORK

Metropolitan region has 752 km of asphalt surfaced road sections with valid data for analysis. For other regions, a very small portion (<40 km for most the regions) of the network has asphalt surfacing. The distributions of MC for asphalt surfaces for all regions are shown in Figure 4-3. The average MC values grouped by deflection ranges are also presented in Table 4-2.

Figure 4-3: Marginal cost distribution by region for Asphalt surfaced pavements (cents/esa.km)

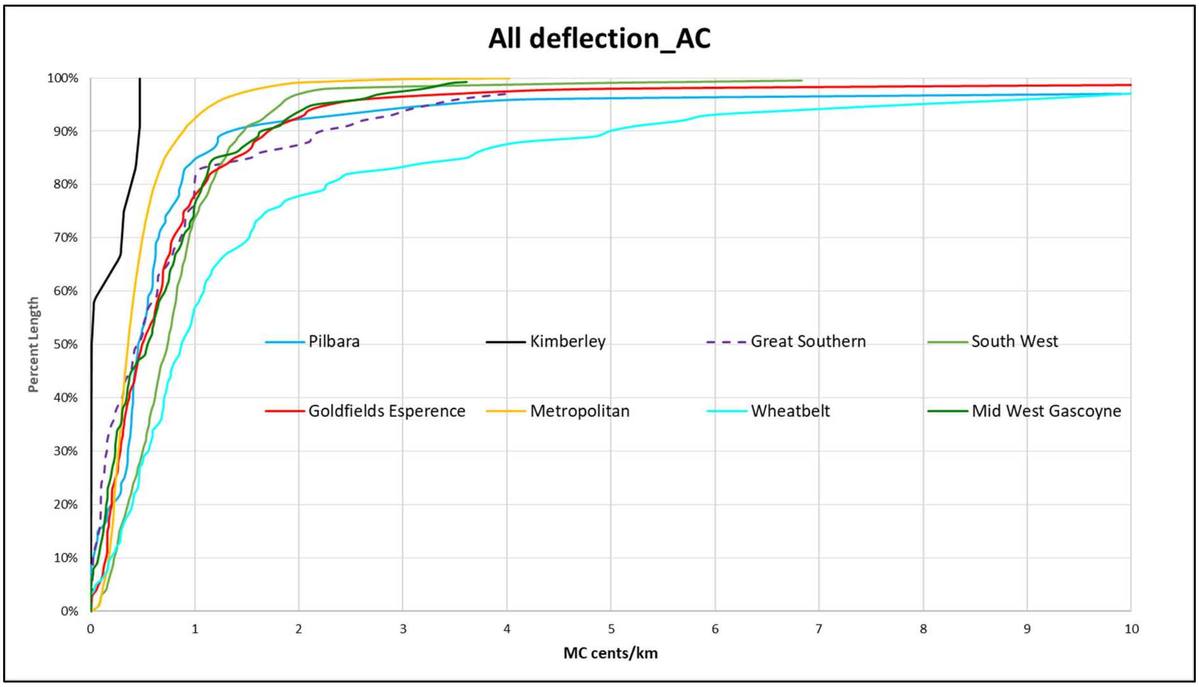


Table 4-2 Average MC values for regions grouped by deflection-asphalt surface (cents/esa.km)

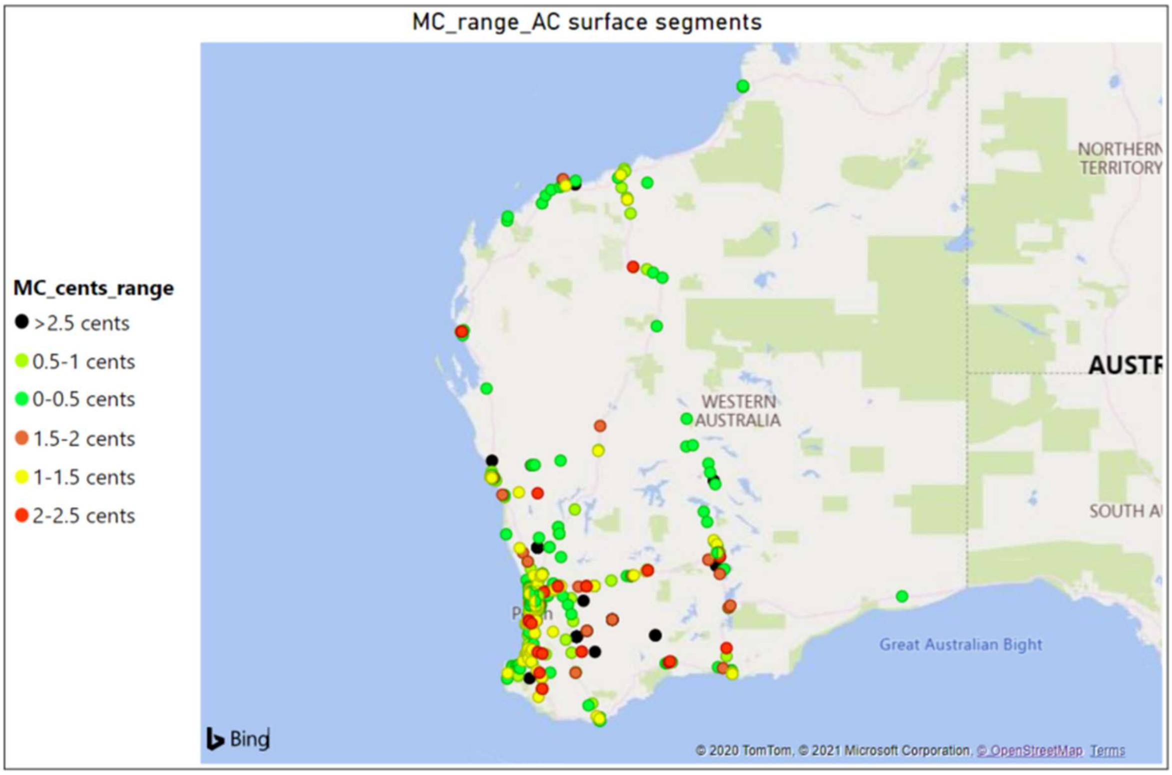
Deflection (micron)	Goldfields Esperance	Great Southern	Kimberley	Metropolitan	Mid-West Gascoyne	Pilbara	South West	Wheat belt
<500	0.51	0.44	0.12	0.45	0.57	0.41	0.76	0.89
500-1000	1.70	1.53	0.43	1.25	1.32	1.81	1.65	2.42
>1000	6.32	2.23			0.72	1.62	3.35	5.23

Observations from Figure 4-3 and Table 4-2 yield similar findings as sealed surface sections with

- MC distribution for the asphalt surfaced network ranges from 0-10 cents/km. For all regions, the 50th percentile MC values are less than 1 cent/esa.km
- Higher deflection ranges are generally associated with higher Marginal cost.

Mapping of marginal cost ranges for each 100-meter segments on MRWA road network (asphalt surfaced) is presented in Figure 4-4 showing variations across the MRWA network.

Figure 4-4: Mapping of Marginal cost ranges on MRWA road network-asphalt surfaced segments



4.4 MARGINAL COST COMPARISON- PILOT NETWORK SEGMENTS

In addition to the full network analysis, average marginal cost values for the pilot network segments (Step 2 of the project , see Section 2.2.2) using the final PMS setup has been calculated and presented in Table 4-3 and Table 4-4 separately for sealed surface and asphalt road sections.

Table 4-3 Marginal cost-sealed surfaced sections - pilot network

Average MC (cents/esa km)	Rainfall ranges		
Deflection Range	**200-500**	**500-800**	**800-1200**
<500	0.68	1.03	1.61
500-1000	0.76	1.60	2.98
>1000	0.75	2.05	4.89

Table 4-4 Marginal asphalt sections - pilot network

Average MC (cents/esa km)	Rainfall range
Deflection range	**200-500**
<500	0.73
500-1000	1.65
>1000	1.98

When Table 4-3 and Table 4-4 are compared with Table 2-6 , it is found that the average marginal cost values using modified PMS setup are almost half than the values obtained during preliminary analysis. This is a result of using less expensive treatments (lower unit rates) along with modified treatment trigger definitions as currently used by MRWA.

5 ESTIMATED BENEFITS TO HEAVY VEHICLE OPERATORS

5.1 GENERAL

Consideration of the benefits to heavy vehicle (HV) operators of a cost recovery process was investigated by computing the road user cost savings, both total savings and HV user specific savings, associated with a well-managed road network and corresponding road preservation funding with alternative funding levels. The rationale is a well-managed road network and corresponding road preservation funding should deliver benefits (ideally) to vehicle operators by reducing road user costs, but additional funding may be required thus warranting a user charge which for the purposes of this component of the study is represented by a marginal cost of road wear.

To estimate relative benefits, this involved determining the road user costs associated with different funding levels, and therefore different future road conditions.

The dTIMS analysis set-up used was the same as that for the final marginal cost analysis. However, rather than employing a single budget scenario, the analysis investigated three funding levels which represented unlimited funding, i.e. the optimum level of funding to support target levels of service, and two lower funding levels, namely 80% and 60% of the unlimited finding. This was undertaken to determine whether increases in funding, supported by additional revenue collection, would deliver benefits to road users, particularly heavy vehicle operators. If this proves to be the case, then 'selling the message' that road user charging could deliver net benefits to operators could prove positive provided, of course, that funds are hypothecated to maintain those parts of the network from which the revenue is derived.

5.2 DEFINITION AND DETERMINATION OF PRODUCTIVITY BENEFITS

Productivity benefits (PB_HV) are defined as road user cost savings gained by heavy vehicle operators from improved road conditions, including associated vehicle operating costs and time savings.

In this study PB_HV are reported as the benefit per HV.km (cents) and the benefit per HV esa.km (cents) relative to a constrained budget, defined for reporting purposes as 60% of the unlimited budget determined necessary to fulfil condition-based level of service targets for a particular road category.

The net productivity benefits (NPB_HV), which account for both user savings and marginal costs (a user charge) are reported as the PB_HV less the computed marginal cost of road wear, i.e. NPB_HV per esa.km = PB_HV per esa.km less MC per esa.km.

As stated, the estimated benefits are relative to a constrained budget which is the usual case, i.e. few authorities have sufficient budget to support desirable service levels. A question can be posed with regard to the level of budget constraint as constraints vary, with the reference value of 60% chosen as a likely worst case.

For this study, user costs have been determined for each 100m analysis section, and therefore these can be examined along with road agency and marginal cost at a detailed level. For the purposes of the examples presented below the respective costs are aggregated for each case study, or sub-study as described below.

5.3 CASE STUDY EXAMPLES AND ANALYSIS

Two regions from the pilot-network used in the earlier stages of this study (Step 2), representing two road sections in Great Southern (approx. 25 km length), and Kimberley (approx.87 km length), were employed for the purposes of this task.

The analysis involved the following:

1. Removing the treat at trigger point constraints in the dTIMS set-up.
2. Running dTIMS based on a 50-year analysis to allow dTIMS freedom to generate multiple strategies which meet the LoS criteria.
3. Optimising the strategies for an unlimited budget.
4. Determining the average road agency budget for the first 20 years as the 100% levelised (unlimited) budget.
5. Undertaking further optimisation employing budget scenarios equal to 80% and 60% of the levelised unlimited budget for first 20 years, with unconstrained funding thereafter. The rationale for this approach is budget constraint should not be perpetual, with a rational approach being eventually to fully apply appropriate standards.
6. Computing the road agency costs (RAC), road user costs (RUC), separated into all vehicles and HV only, and total transport costs (TTC) of each scenario.
7. Computing and presenting the results employing the following metrics:
    - The RAC, RUC (All vehicles and HV only) and TTC, and associated savings and marginal benefit cost ratio relative to the lowest budget scenario.
    - The total equivalent standard axles (in millions) and vehicle kilometres travelled (All and HV)
    - The productivity benefits (PB_HV) and net productivity benefits (NPB_HV), as described in section 5.2.

All metrics, including traffic as vkt, esa, etc, are reported in discounted present values (PV).

5.4 RESULTS

The results for the two case studies are presented in Table 5-1, and Table 5-2

Table 5-1: Estimation of productivity benefits: computed metrics for Great Southern Case Study

Metric	Unlimited budget	80% unlimited	60% unlimited
Average of AV_IRI_20 years	3.63	3.91	4.00
Average of AV_IRI full analysis	3.21	3.25	3.26
Sum of PV_RUC	62,668,258	63,449,152	63,692,620
Sum of PV_HV_RUC	15,464,174	15,639,959	15,695,855
Sum of PV_RAC	2,677,427	2,460,381	2,401,860
RUC Savings	1,024,362	243,468	-
RUC HV Savings	231,681	55,896	-
Sum of PV_TTC	65,345,684	65,909,532	66,094,480
TTC Savings	748,796	184,948	0
dRAC	275,566	58,520	0
NPV/c	2.72	3.16	-
Sum of PV_MESA.km	13.42	13.42	13.42
Sum of PV_HV_km	17,861,524	17,861,524	17,861,524
Benefit per HV ESA.km (cents)	1.73	0.42	-
Marginal cost per esa.km	2.57	2.57	2.57
Net Benefit per HV per esa.km	-0.84	-2.15	-2.57

Table 5-2: Estimation of productivity benefits: computed metrics for Kimberley Case Study

Metric	Unlimited budget	80% unlimited	60% unlimited
Average of AV_IRI_20 years	2.68	3.00	3.36
Average of AV_IRI full analysis	2.78	2.87	3.02

Sum of PV_RUC	55,851,859	56,416,438	57,288,812
Sum of PV_HV_RUC	24,940,476	25,209,497	25,608,380
Sum of PV_RAC	4,069,546	3,550,268	3,082,160
RUC Savings	1,436,953	872,374	-
RUC HV Savings	667,904	398,884	-
Sum of PV_TTC	59,921,405	59,966,706	60,370,972
TTC Savings	449,567	404,266	0
dRAC	987,386	468,108	0
NPV/c	0.46	0.86	
Sum of PV_MESA.km	34.02	34.02	34.02
Sum of PV_HV_km	17,271,738	17,271,738	17,271,738
Benefit per HV ESA.km (cents)	1.96	1.17	-
Marginal cost per esa.km	1.60	1.60	1.60
Net Benefit per HV per esa.km	0.36	-0.43	-1.60

The resulting findings are as follows:

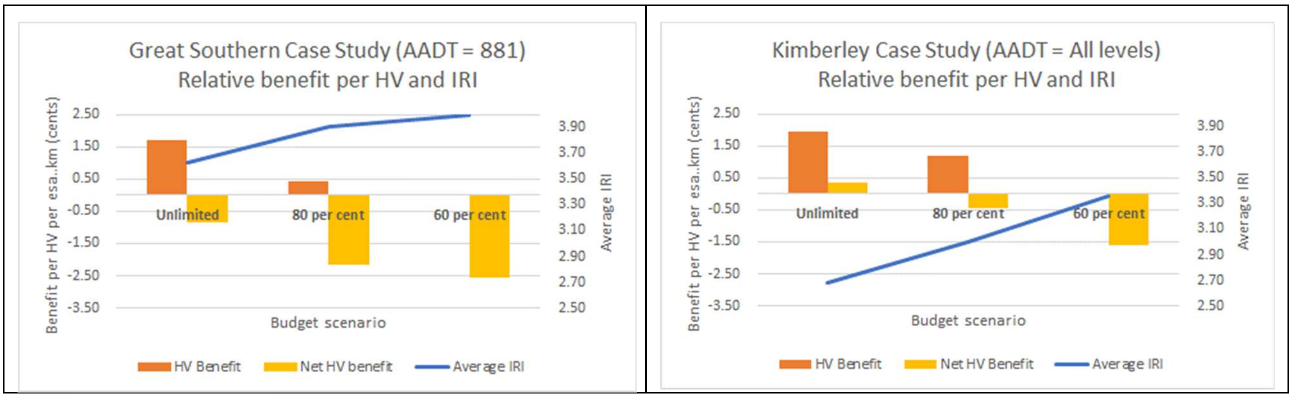
c) For the Great Southern example, the marginal cost of road wear (2.6 cents per esa.km) was greater than the estimated productivity saving (1.7 cents per esa.km), resulting in a net productivity loss of approximately 0.8 cents per esa.km.
This example also had the following features reflecting the characteristics (including pavement history and condition, strength, climate, traffic, etc) of the case study road chosen, the LoS policy applied (CW), and the impact of these on road user costs and total transport costs:
    - The marginal cost rate is high (approximately 90th percentile value for the region) with this most probably a consequence of the combination of the current condition, pavement strength, and legacy construction standards.
    - Whereas the economic analysis demonstrates that the unlimited budget minimises total transport costs, and road user costs, the reduction in user costs is insufficient to offset the cost of preservation and renewal attributable to HV's.
    - The average IRI values (20 years) are shown to vary from approximately 3.6 (Unlimited budget) to 4 (60% budget) which are well below the rehabilitation limit of 5.3 IRI for a CW road category, with the lower value delivering TTC savings and RUC savings.
    - The unit cost rates in Great Southern are also relatively high, with this impacting marginal costs. The average road user cost per heavy vehicle is also relatively low, with total numbers also low. This combination results in less opportunity for net productivity benefits.

d) For Kimberley, the marginal cost of road wear (1.6 cents per esa.km) is slightly less than the estimated productivity saving (1.96 cents per esa.km), resulting in a net productivity benefit of 0.36 cents per esa.km.
The case study had the following features reflecting its particular characteristics and the impact of these on road user costs and total transport costs:
    - In this case the economic analysis demonstrates that the unlimited budget also minimises total transport costs, and road user costs, and delivers net HV-related road user cost savings per esa.km, albeit marginal savings.
    - This also reflects the LoS policy (BW) which is associated with a lower maximum roughness, with the achievement of this most likely influenced by the lower costs of major treatments being some 26% less than the Great Southern rates (Table 2-9).

- The average IRI values (20 years) are shown to vary from approximately 2.7 (Unlimited budget) to 3.4 (60% budget) which are well below the rehabilitation limit of 4.2 IRI for a BW road category, with the lower value delivering TTC savings and RUC savings.
- A characteristic of this case study is the substantial variation in traffic levels, with these varying from around 200 AADT to over 4000 AADT. If considered separately, net benefits vary from a low of almost zero to approximately 1.3 cents per esa.km respectively, i.e. they increase with increasing road use.
- A further characteristic of this case study is, the minimum TTC for the sections of road displaying different traffic levels (four in total) showed that two of these coincided with unlimited funding (approx. 620 and 4000 AADT) and two coincided with the 80 percent budget scenario (approx. 200 and 680 AADT). This illustrates a possible issue with the level of policy applied, i.e. it does not coincide with minimum transport costs for each individual segment, although it does for the road examined.

Finally, the variation in relative HV benefits by budget scenario is shown for the two case studies, with the average IRI (20 years) also shown. This serves to illustrate that net benefits are possible, but this will depend on multiple factors.

Figure 5-1: Illustration of the relative benefits to HV operators by budget scenario and road condition for two cases



5.5 CONCLUDING REMARKS

From the above, even considering the limited scope of the examples, it is clear that a number of factors impact marginal costs and potential productivity benefits, and include:

a) The LoS policy impacts road user costs, and if it can be achieved at a lower cost as determined by unit treatment costs, then marginal costs will be lower and net benefits are likely to be higher.
b) Underlying assumptions/factors including the road deterioration models employed, these being based on national studies with account taken of the observed relatively low rate of structural deterioration in Western Australia, and the life of surfacings, being significantly longer than national estimates.

Based on the above, it is recommended that further work in this area only proceeds once the findings of the ongoing Improved Decision Making (IDM) project are available to provide a more confident basis for forward modelling of the most dominant modes of distress warranting functional and structural treatments, and explanatory factors such as deflection, traffic, environment etc. This would impact the level of agency costs, and therefore marginal costs, and road user costs and consequently productivity benefits. A future study should also examine the impact of the current LoS policy and a minimum total transport cost based economic LoS.

6 COMMUNICATIONS TOOL FOR INVESTIGATING MARGINAL COSTS

6.1 GENERAL

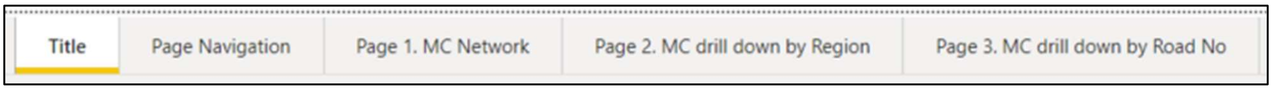
As a part of the project deliverable, an interactive communication tool incorporating the marginal cost outputs for MRWA road network (road segments with valid 2018 TSD condition data) has been prepared using Microsoft Power BI software. The tool provides the opportunity to review the marginal cost values at network, regional and road section level. It also provides the opportunity to review the changes in Marginal cost with the changes in different parameters such as road link category, traffic, deflection, rainfall, surface type, etc. as appropriate.

6.2 CONTENTS OF THE TOOL

The Power BI tool consists of five separate tabs (Figure 6-1).

- Title
- Page Navigation
- Page 1-MC Network
- Page 2-MC drill down by region
- Page 3- MC drill down by Road No

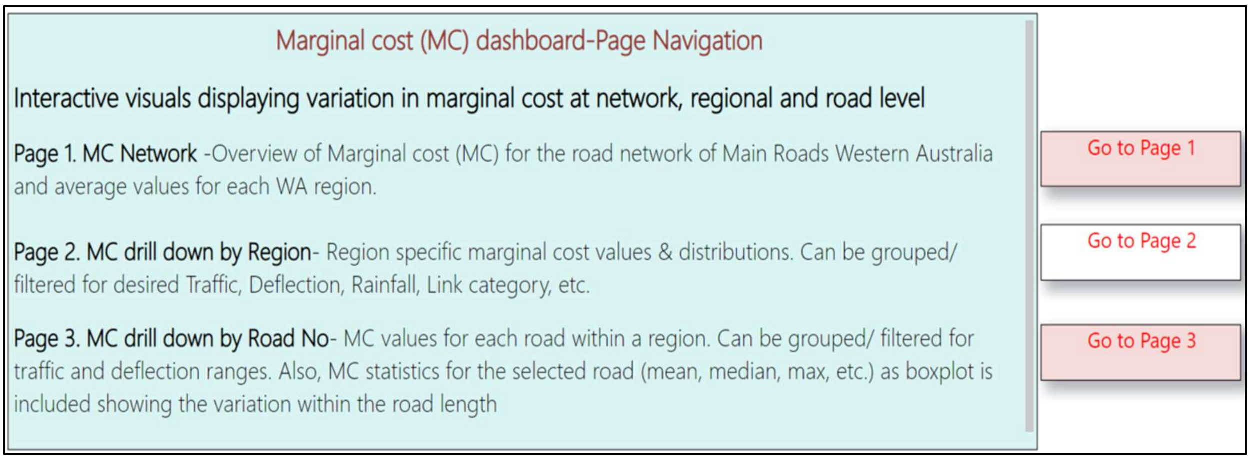
Figure 6-1: Pages in the interactive Power BI tool



6.3 NAVIGATING THROUGH THE OUTPUTS

“Page Navigation” (see Figure 6-2Figure 6-2) tab introduces the users to the contents on each tab. User can also jump to a specific tab by CTRL+ clicking the respective bookmark buttons for the pages in the navigation window.

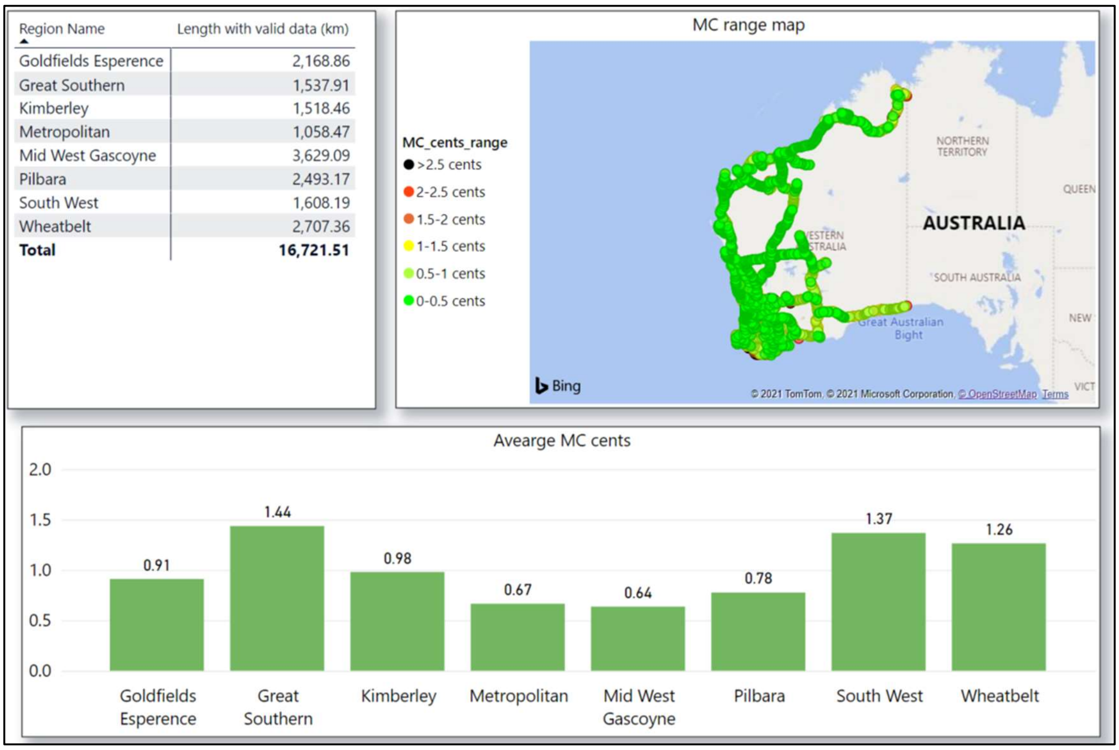
Figure 6-2: Page Navigation window



6.3.1 PAGE 1 MC NETWORK

Provides an overview of Marginal cost (MC) for the road network of Main Roads Western Australia in a map and average values for each WA region. Associated road lengths (length with valid condition data) for each region has also been tabulated (Figure 6-3)

Figure 6-3: Page 1 MC network



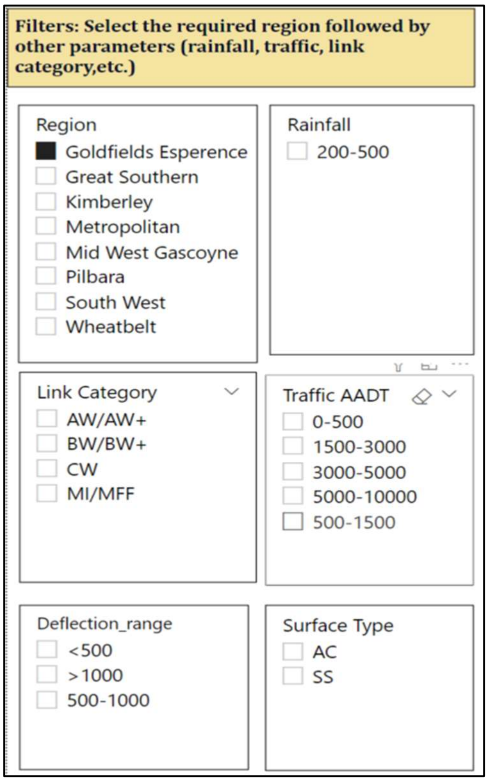
Page 1 is a "read only" page with no filter available for selection.

6.3.2 PAGE 2 MC DRILL DOWN BY REGION

Page 2 displays region specific marginal cost values & distributions. Outputs can be grouped/ filtered for desired Traffic, Deflection, Rainfall, Link category, Surface type etc.

User needs to select the required filters on the left of the page. "Region" of interest should be selected first followed by link category, traffic, surface type, etc, as required (see Figure 6-4).

Figure 6-4: Page 2- MC drill down by Region- Filters



Once the filters are picked, output MC distributions and the map for the region will refresh automatically (Figure 6-5).

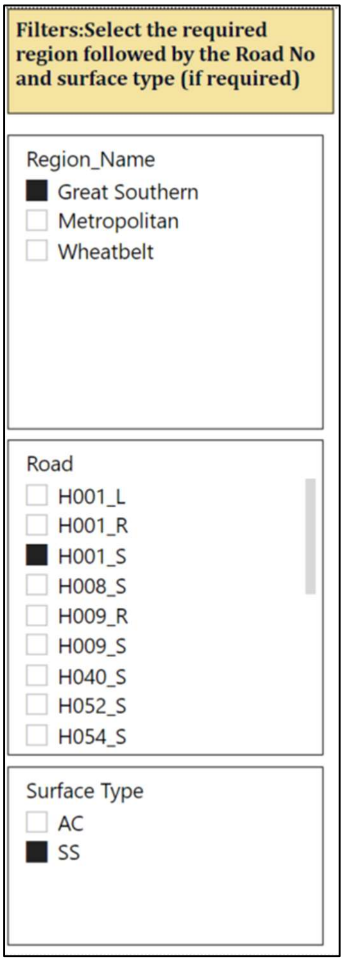
Figure 6-5: Page 2- MC drill down by Region- Outputs based on selected filters

6.3.3 PAGE 3 MC DRILL DOWN BY ROAD NO

Page 3 outlines MC outputs (by traffic class and deflection range) for each road no. within a region. Outputs can be grouped/ filtered for desired surface type. Also, MC statistics for the selected road no. (e.g., mean, median, max, etc.) is included as boxplot showing the variation within the road length.

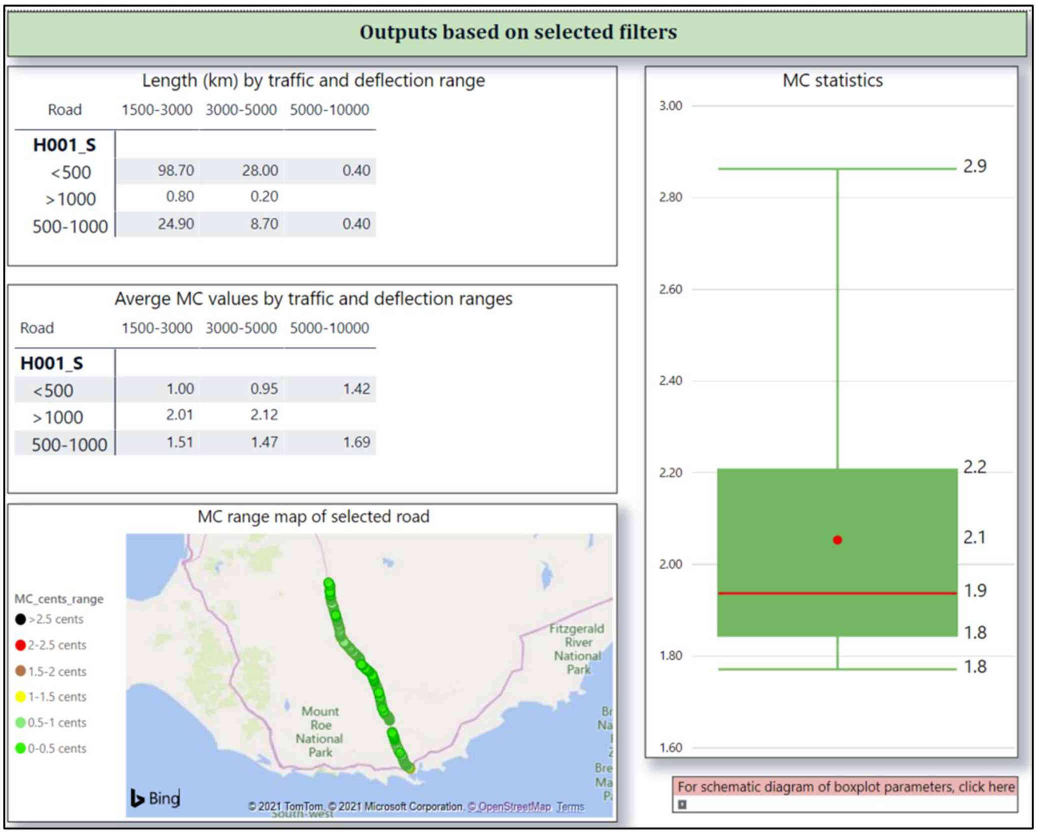
User needs to select the required filters on the left of the page. “Region” should be selected first followed by “Road No”. Surface type, if required, can also be selected (Figure 6-6).

Figure 6-6: Page 3- MC drill down by Road No- Filters



Once the region and road no are chosen, MC outputs for the selected road no. will refresh automatically (Figure 6-7).

Figure 6-7: Page 3- MC drill down by Road No- Outputs based on selected filters



Note: A simple schematic diagram explaining different boxplot parameters have also been added to the tool to help users interpreting the boxplot outputs.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

1. This study successfully adapted and applied an established national methodology for the determination of the marginal cost of road wear (in cents per esa.km) using available road condition, pavement strength, inventory, traffic, unit cost and environmental data representing a substantial proportion of Main Roads' network. The full application of the methodology was preceded by a series of investigations involving the assembly of the analysis data, a pilot analysis of selected roads in three regions, further investigations to establish a final set-up and final analysis and reporting of marginal costs determined for individual 100m road segments.
2. Amongst the novel considerations in finalising the analysis set up was the introduction of a method aimed at accounting for remaining asset life beyond the period of the analysis, and where minimum treatment intervals meant that a higher cost treatment was required when the trigger was exceeded. This was achieved by incorporating calculations of asset consumption/salvage value and penalty costs in the dTIMS analysis tool chosen for this analysis. This meant that account could be taken of the long service lives possible from WA pavements, which can deliver further benefits in future thereby reducing marginal costs.
3. For the sprayed seal network, it was found that for all regions, the 50th percentile MC values are between 0.5 and 1 cent/esa.km, with the overall low values of marginal cost explained by the nature of WA pavements which are quite strong with relatively low deflection and a longer pavement life. In addition, treatment unit rates associated with the asset preservation strategies employed used by MRWA, including relatively low-cost profile correction treatments, are quite low when compared with other Australian road authorities, resulting in overall low MC values.
4. For the asphalt network, it was found that the distribution of MC values is also low, with the 50th percentile MC values being below 1 cent/esa.km. Higher deflection ranges are generally associated with higher marginal cost.
5. Comparing across WA regions, Great Southern has the highest overall MC values (distribution) while Mid-West Gascoyne has the lowest overall MC values (distribution). Climatic factors, such as TMI may be a contributing factor explaining this trend. Great Southern region has the wettest TMI within all WA regions while Mid-West Gascoyne has the driest TMI values. Different unit rates used by regions also contribute to the variation of MC across the regions. Higher deflection ranges are also associated with higher MC values. This is expected as deflection is directly related to the strength of the pavement and its load carrying capacity.
6. An investigation of productivity benefits, representing the net cost to heavy vehicle operators based on the estimated road user cost savings delivered by a fully funded asset preservation and renewal program and the marginal cost of road wear, was also undertaken. This showed that whilst net productivity benefits were possible, with this depending on a number of factors, productivity losses could also occur. For the case studies examined, the factors which supported net benefits included lower road agency costs resulting from lower treatment unit rates, lower intervention levels consistent with a higher level of service, and corresponding lower road user costs where funding is unconstrained. The rationale is that the revenue generated by application of a user charge based on marginal costs should be used to directly support the fulfilment of service levels.
7. A communications tool has been developed which allows practitioners and managers to assess the marginal cost of road wear allowing interrogation of road specific, regional, and state-wide variations of asset risks from heavy vehicles.

7.2 RECOMMENDATIONS

1. The results of the marginal cost component of this study should be communicated to asset managers and heavy vehicle access managers and applied in assessing risks to road pavement assets, and the likely cost impacts of heavy vehicle use.
2. Further research is warranted once the findings of the ongoing Improved Decision Making (IDM) project are available. This would provide a more confident basis for forward modelling of the most dominant modes of distress warranting functional and structural treatments, and explanatory factors such as deflection, traffic, environment etc. This would impact the level of agency costs, and therefore marginal costs, and road user costs and consequently productivity benefits.
3. A future study should also examine the impact of the current LoS policy, and a minimum total transport cost based economic LoS, with this undertaken once improved road deterioration models are available from the IDM project.

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