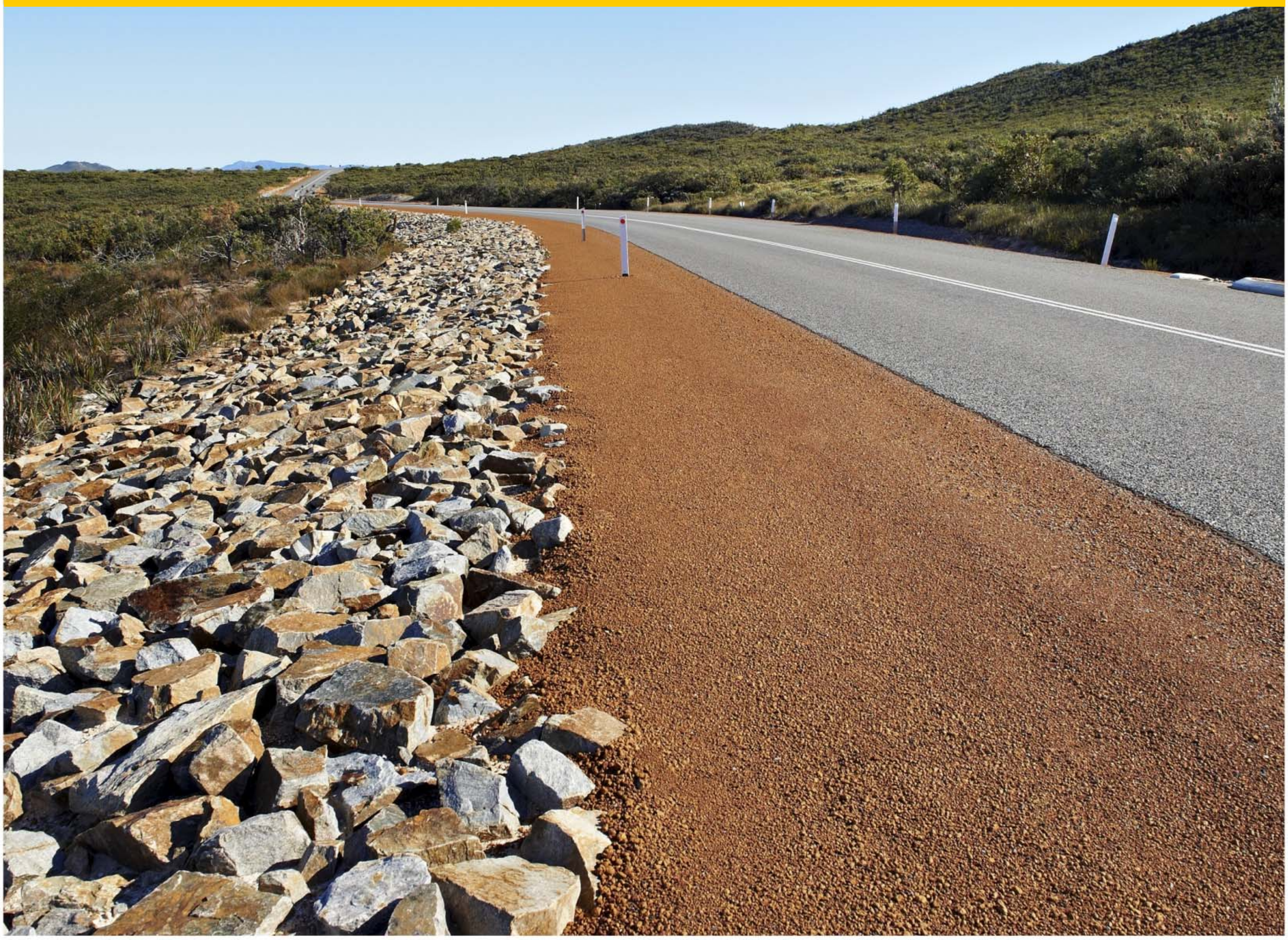
WAPARC

Western Australian Pavement Asset Research Centre

Whole-of-life-cycle Costing of Road Pavement Configurations

2011/01



CONTRACT REPORT

Whole-of-life-cycle Costing of Road Pavement Configurations

Project No: 004408

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for Main Roads WA

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SUMMARY

Until 2008, heavily trafficked urban roads in Western Australia were predominantly granular pavements with thin (60 mm or less) asphalt surfacings. From the 1990s, the granular basecourse material was often modified with cement to increase its stiffness: the material is hydrated cement treated crushed rock base (HCTCRB). This modification of the basecourse sometimes led to premature cracking and performance issues.

With significantly increased traffic loadings full-depth asphalt is now the most commonly used pavement type on heavily loaded urban roads. In October 2007, ARRB prepared a whole-of-life-cycle cost (WOLCC) analysis for Main Roads Western Australia of the pavement options for the Reid Highway project (West Swan Road to GNH). That WOLCC analysis showed that full-depth asphalt pavements may be an economically viable alternative to modified granular pavements.

Since that report, Main Roads WA has further refined design and specification procedures, particularly in relation to HCTCRB. Main Roads WA consider it is time to review this 2007 analysis for a broader range of traffic loadings, pavement configurations and climatic conditions and using better cost information that is now available from recent projects.

The objective of this new WOLCC analysis is to provide recommendations on the optimal pavement configuration for pavements with asphalt wearing courses. The review also had the objective of providing guidance about when concrete pavements are the preferred pavement option (i.e. traffic loading or climatic conditions). Excluded from the analysis was sprayed seal surfaced unbound pavements which are known to have the lowest WOLCC for rural roads.

The project involved estimating the initial construction costs and WOLCC road agency costs for a wide range of asphalt or concrete surfaced pavement structures for four temperature regimes, a range of design traffic speeds and a wide range of subgrade strengths. The results are reported herein and a WOLCC Calculator developed.

Based on the findings of this report, Main Roads WA will decide whether to proceed with the estimation of the road user costs and hence the total WOLCC.

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1 INTRODUCTION

Until 2008, heavily trafficked urban roads in Western Australia were predominantly granular pavements with thin (60 mm or less) asphalt surfacings. From the 1990s, the granular basecourse material was often modified with cement to increase its stiffness: the material is hydrated cement treated crushed rock base (HCTCRB). This modification of the basecourse sometimes led to premature cracking and performance issues.

In October 2007 ARRB prepared a whole-of-life-cycle cost (WOLCC) analysis for Main Roads Western Australia of the pavement options for the Reid Highway project (West Swan Road to GNH) (Jameson 2007). That WOLCC analysis showed that full-depth asphalt pavements may be an economically viable alternative to modified granular pavements. Full-depth asphalt is now the most commonly used pavement type on heavily loaded urban roads in the Perth region.

Main Roads WA considers it is time to review this analysis using:

- a wider range of pavement and surfacings types over a wider range of climates, traffic speeds and loadings
- improved pavement design procedures
- better understanding about performance and maintenance requirements
- better cost information that is now available from recent projects.

Accordingly, ARRB was commissioned to undertake a comprehensive investigation of WOLCC by means of the Western Australian Pavement Asset Research Centre (WAPARC) project 2011/01 *Optimal Pavement Configurations with Asphalt Wearing Courses*.

The objective of the review was to provide recommendations on the optimal pavement configuration for pavements with asphalt wearing courses based on the above factors. Guidance was also required about when concrete pavements are the preferred pavement option (i.e. traffic loading or climatic conditions). Excluded from the review was sprayed seal surfaced unbound pavements which are known to have the lowest WOLCC for rural roads.

The project was limited to estimating the whole-of-life road agency costs. Based on the findings of road agency costs, Main Roads WA will decide whether to proceed with the estimation of the road user costs and hence the total of road agency and road user WOLCC.

The following topics are discussed:

- method used for economic comparison (Section 2)
- pavement structures investigated (Section 3)
- initial construction costs (Section 4)
- maintenance scenarios (Section 5)
- maintenance costs (Section 6)
- residual value at the end of the analysis period (Section 7)
- road agency whole-of-life costs (Section 8)
- summary and conclusions (Section 9).

2 METHOD FOR ECONOMIC COMPARISON

The purpose, in an economic comparison, is to evaluate alternative designs primarily according to the criterion of minimum total (whole-of-life) cost, giving due consideration also to the safety and service provided to road users and others who may be affected by the road or its construction.

There are several methods for economic comparison of alternative designs. The 'present worth' method outlined in Chapter 10 of the Guide to Pavement Technology Part 2 (Austroads 2012) was adopted for this project. The present worth method effectively allows for both uniform series and sporadic events (e.g. routine and periodic maintenance) which will occur during the service life of the pavement. With the present worth method, all costs are converted into capital sums of money which, invested now for an analysis period, would provide the sums necessary for construction of a project and subsequent maintenance during the period.

The present worth of costs (PWOC) can be calculated as follows:

$$PWOC = C + \sum_{i} M_i (1+r)^{-x_i} - S(1+r)^{-z} \quad (1)$$

where

PWOC	=	present worth of costs
C	=	present cost of initial construction
M_i	=	cost of the i^{th} maintenance and / or rehabilitation measure
r	=	real discount rate
x_i	=	number of years from the present to the i^{th} maintenance and/or rehabilitation measure, within the analysis period
z	=	analysis period
S	=	salvage or residual value of pavement at the end of the analysis period expressed in terms of present values.

In estimating present worth the principal elements are:

- construction costs
- maintenance and rehabilitation costs, including routine periodic maintenance and structural rehabilitation
- residual value of the pavement at the end of the analysis period
- real discount rate
- analysis period.

The process of deflating future costs assumes that funds will be available over the analysis period at a level consistent with the adopted discount rate. As this may not occur, the sensitivity of the model to a range of discount rates should also be investigated.

The economic model may also not account for substantial differences in the social, political or environment impacts of future maintenance and rehabilitation activities associated with designs. For instance, one alternative may require reconstruction involving a total road closure at the end of the analysis period whereas another may be rehabilitated under traffic but on a more frequent basis. Both would involve some level of social disruption for the community that may not be properly reflected in the economic comparison.

3 PAVEMENT STRUCTURES INVESTIGATED

3.1 Introduction

In rural areas, sprayed bituminous seal surfaced unbound granular materials are well known to be the pavement type with the lowest WOLCC. Consequently, Main Roads WA excluded these types of pavements from the scope of this project.

The project addressed pavements used for urban arterials, highways and freeways where sprayed seal unbound granular materials are not suitable due to noise and higher routine maintenance demands. For such roads an asphalt surfacing is now commonly provided for pavements under Main Roads WA control. Concrete pavements are also an option that Main Roads WA requested be reviewed.

The pavement types and surfacings types included in the costing were selected and designed by Main Roads WA using Engineering Road Note 9 (ERN9), (Main Roads WA 2012) plus the supplementary rules described below.

3.2 Pavement and Surfacing Types Considered

The following pavement types were considered in the analysis:

- Pavement Type 1a (Granular – CRB): Thin asphalt with crushed rock base (CRB) and granular subbase; two binder options investigated for the 30 mm of DGA10 (Class 170 bitumen, A15E polymer modified binder)
- Pavement Type 1a5 (Granular – CRB): as per Type 1a except that the pavement is designed with a 5 year asphalt fatigue life rather than 15 years (this pavement type only applies to Main Roads WA experience with pavements on sand subgrades (CBR=12%) in the Perth metropolitan region); two binder options investigated for the 30 mm of DGA10 (Class 170 bitumen, A15E polymer modified binder)
- Pavement Type 1b (Granular - HCTCRB): Thin asphalt with hydrated cement treated crushed rock base (HCTCRB) and granular subbase; two binder options investigated for the 30 mm of DGA10 (Class 170 bitumen, A15E polymer modified binder)
- Pavement Type 1c (Granular - HCTCRB): Thin asphalt with hydrated cement treated crushed rock base (HCTCRB) and cement treated granular subbase; two binder options investigated for the 30 mm of DGA10 (Class 170 bitumen, A15E polymer modified binder)
- Pavement type 1d (Granular - HCTCRB): Thin asphalt with full-depth hydrated cement treated crushed rock base (HCTCRB); two binder options investigated for the 30 mm of DGA10 (Class 170 bitumen, A15E polymer modified binder)
- Pavement Type 2 (Full-Depth Asphalt): Full-depth asphalt, granular subbase; three binder options investigated for the top 90 mm of DGA14 (Class 320 bitumen, A15E and A35P polymer modified binders)
- Pavement Type 3 (Composite): Flexible and rigid composite, comprising a minimum 175 mm thickness of dense graded asphalt; lean concrete subbase (LCS); three binder options investigated for the top 90 mm of DGA14 (Class 320 bitumen, A15E and A35P polymer modified binders)

- Pavement Type 4 (Deep Strength Asphalt): Minimum of 175 mm dense graded asphalt; cement treated crushed rock subbase; three binder options investigated for the top 90 mm of DGA14 (Class 320 bitumen, A15E and A35P polymer modified binders)
- Pavement Type 5 (PCP): Plain concrete pavement
- Pavement Type 6 (CRCP): Continuously reinforced concrete pavements
- Pavement Type 6a (CRCP): Continuously reinforced concrete pavements with 30 mm open graded asphalt surfacing.

Note that HCTCRB is a crushed rock base modified with a low percentage (2%) of cement added during manufacture, which is then hydrated, stockpiled and reworked before field placement.

The following surfacing types were considered in the analysis:

- 10 mm size dense graded asphalt (DGA10): used only on granular pavements (Type 1a-1d) as a wearing course for mid-block sections for speeds up to 80 km/h, or as a layer underlying open graded asphalt for higher speeds
- 14 mm size dense graded asphalt (DGA14): used on granular and asphalt pavements (Types 1a-1d, 2, 3 and 4) as a wearing course at intersections; and on asphalt pavements as a wearing course for mid-block sections for speeds up to 90 km/h, or as a layer underlying open graded asphalt for higher speeds
- 10 mm size open graded asphalt (OGA10): used on granular and asphalt pavements (Types 1a-1d, 2, 3 and 4) as a wearing course for speeds higher than 90 km/h or where open graded asphalt is required for noise reduction (including on CRCP Pavement Type 6a).

Pavement structural details are given in Table 3.1, Table 3.2 and Table 3.3. All pavements were designed by Main Roads WA in accordance with ERN9 (Main Roads WA 2012) and with supplementary rules as defined in the following tables. There is an anomaly in the current design model for thin asphalt surfaced pavements in that the maximum allowable traffic loading in terms of fatigue increases as the subgrade modulus decreases. To address this anomaly, for each pavement configuration with a subgrade design CBR less than 12%, the maximum allowable loading was limited such that it did not exceed that for a subgrade design CBR of 12%. Appendix B details the asphalt design moduli and volume of binders used in the calculations.

Note that for some pavement configurations the use of polymer modified binder in the upper asphalt layers reduces the required pavement thickness and/or increases the maximum allowable loading to fatigue. It should be noted that ERN9 includes the following requirement:

> Whilst polymer modified binders must be used to manage the risk of premature cracking, fatigue and/or rutting, the pavement thickness must not be less than would be determined had the specified unmodified binder been used, unless approved otherwise by the Principal.

Table 3.1: Pavement types 1a, 1a5, 1b, 1c and 1d configurations

Pavement type	Asphalt surfacing options	Granular base	Subbase
1a and 1a5	30 mm DGA10 (C170)	Crushed rock base E_{top} = 500 MPa minimum base thickness Austroads (2012) Figure 8.4	Granular subbase minimum thickness 300 mm when subgrade design CBR < 10% and 200 mm when ≥ 10%
	30 mm DGA10 (A15E)		
	40 mm DGA14 (C320)		
	40 mm DGA14 (A15E)		
	30 mm OGA10 (on 30 mm DGA10 (C170)		
	30 mm OGA10 on 30 mm DGA10 (A15E)		
1b	30 mm DGA10 (C170)	Hydrated cemented treated crushed rock base (HCTCRB) Thickness determined as the maximum of thickness modelled in two ways: **HCTCRB modelled as modified material:** E_{top} = 1000 MPa minimum thickness is $3/5^{th}$ the total thickness of base and subbase up to a maximum 250 mm **HCTCRB as a cemented material:** E = 2000 MPa	Granular subbase minimum thickness 300 mm when subgrade design CBR < 10% and 200 mm when ≥ 10%
	30 mm DGA10 (A15E)		
	40 mm DGA14 (C320)		
	40 mm DGA14 (A15E)		
	30 mm OGA10 on 30 mm DGA10 (C170)		
	30 mm OGA10 on 30 mm DGA10 (A15E)		
1c	30 mm DGA10 (C170)	Hydrated cemented treated crushed rock base (HCTCRB) Thickness determined as the maximum of thickness modelled in two ways: **HCTCRB modelled as modified material:** E_{top} = 1000 MPa sublayered in accordance with Austroads Guide **HCTCRB as a cemented material:** E = 2000 MPa	For subgrade design CBR < 10% 150 mm cement treated crushed rock (E = 500 MPa) on 150 mm granular subbase For subgrade design CBR ≥ 10% 200 mm cement treated crushed rock (E = 500 MPa)
	30 mm DGA10 (A15E)		
	40 mm DGA14 (C320)		
	40 mm DGA14 (A15E)		
	30 mm OGA10 on 30 mm DGA10 (C170)		
	30 mm OGA10 on 30 mm DGA10 (A15E)		
1d	30 mm DGA10 (C170)	Hydrated cemented treated crushed rock base (HCTCRB) Thickness determined as the maximum of thickness modelled in three ways: **HCTCRB modelled as modified material:** E_{top} = 1000 MPa sublayered in accordance with Austroads Guide **HCTCRB as a cemented material:** E = 2000 MPa Minimum 230 mm HCTCRB	For subgrade design CBR < 10% minimum 150 mm HCTCRB and 150 mm granular subbase For subgrade design CBR ≥ 10% minimum 200 mm HCTCRB
	30 mm DGA10 (A15E)		
	40 mm DGA14 (C320)		
	40 mm DGA14 (A15E)		
	30 mm OGA10 on 30 mm DGA10 (C170)		
	30 mm OGA10 on 30 mm DGA10 (A15E)		

Table 3.2: Pavement type 2 configurations

Pavement and surface type	Layer 1 (surface)	Layer 2	Layer 3	Layer 4	Layer 5
2 DGA14 surface	40 mm DGA14 (C320)	50 mm DGA14 (C320)	X mm DGA20 (C320), minimum thickness 60 mm	Granular subbase minimum thickness 300 mm when subgrade design CBR < 10% and 200 mm when ≥ 10%	
	40 mm DGA14 (A15E)	50 mm DGA14 (A15E)	X mm DGA20 (C320), minimum thickness 60 mm	Granular subbase minimum thickness 300 mm when subgrade design CBR < 10% and 200 mm when ≥ 10%	
	40 mm DGA14 (A35P)	50 mm DGA14 (A35P)	X mm DGA20 (C320), minimum thickness 60 mm	Granular subbase minimum thickness 300 mm when subgrade design CBR < 10% and 200 mm when ≥ 10%	
2 OGA surface	30 mm OGA10	40 mm DGA14 (C320)	50 mm DGA14 (C320)	X mm DGA20 (C320), minimum thickness 60 mm	Granular subbase minimum thickness 300 mm when subgrade design CBR < 10% and 200 mm when ≥ 10%
	30 mm OGA10	40 mm DGA14 (A15E)	50 mm DGA14 (A15E)	X mm DGA20 (C320), minimum thickness 60 mm	Granular subbase minimum thickness 300 mm when subgrade design CBR < 10% and 200 mm when ≥ 10%
	30 mm OGA10	40 mm DGA14 (A35P)	50 mm DGA14 (A35P)	X mm DGA20 (C320), minimum thickness 60 mm	Granular subbase minimum thickness 300 mm when subgrade design CBR < 10% and 200 mm when ≥ 10%

Table 3.3: Pavement Type 3 configurations

Pavement and surface type	Layer 1 (surface)	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
3 DGA14 surface	40 mm DGA14 (C320)	50 mm DGA14 (C320)	X mm DGA20 (C320), minimum thickness 85 mm	140 - 220 mm lean concrete subbase E = 10 000 MPa (no allowance for post-cracking phase of life)	Granular subbase minimum thickness 300 mm when subgrade design CBR < 10% and 200 mm when ≥ 10%	
	40 mm DGA14 (A15E)	50 mm DGA14 (A15E)	X mm DGA20 (C320), minimum thickness 85 mm	140 - 220 mm lean concrete subbase E = 10 000 MPa (no allowance for post-cracking phase of life)	Granular subbase minimum thickness 300 mm when subgrade design CBR < 10% and 200 mm when ≥ 10%	
	40 mm DGA14 (A35P)	50 mm DGA14 (A35P)	X mm DGA20 (C320), minimum thickness 85 mm	140 - 220 mm lean concrete subbase E = 10 000 MPa (no allowance for post-cracking phase of life)	Granular subbase minimum thickness 300 mm when subgrade design CBR < 10% and 200 mm when ≥ 10%	
3 OGA10 surface	30 mm OGA10	40 mm DGA10 (C320)	50 mm DGA14 (C320)	X mm DGA20 (C320), minimum thickness 85 mm	140 - 220 mm lean concrete subbase E = 10 000 MPa (no allowance for post-cracking phase of life)	Granular subbase minimum thickness 300 mm when subgrade design CBR < 10% and 200 mm when ≥ 10%
	30 mm OGA10	40 mm DGA10 (A15E)	50 mm DGA14 (A15E)	X mm DGA20 (C320), minimum thickness 85 mm	140 - 220 mm lean concrete subbase E = 10 000 MPa (no allowance for post-cracking phase of life)	Granular subbase minimum thickness 300 mm when subgrade design CBR < 10% and 200 mm when ≥ 10%
	30 mm OGA10	40 mm DGA10 (A35P)	50 mm DGA14 (A35P)	X mm DGA20 (C320), minimum thickness 85 mm	140 - 220 mm lean concrete subbase E = 10 000 MPa (no allowance for post-cracking phase of life)	Granular subbase minimum thickness 300 mm when subgrade design CBR < 10% and 200 mm when ≥ 10%

Table 3.4: Pavement Type 4 configurations

Pavement and surface type	Layer 1 (surface)	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
4 DGA14 surface	40 mm DGA14 (C320)	50 mm DGA14 (C320)	X mm DGA20 (C320), minimum thickness 85 mm	For subgrade design CBR < 10% 150 mm cement treated crushed rock (E = 500 MPa) For subgrade design CBR ≥ 10% 200 mm cement treated crushed rock (E = 500 MPa)	For subgrade design CBR < 10% 150 mm granular subbase	
	40 mm DGA14 (A15E)	50 mm DGA14 (A15E)	X mm DGA20 (C320), minimum thickness 85 mm	For subgrade design CBR < 10% 150 mm cement treated crushed rock (E = 500 MPa) For subgrade design CBR ≥ 10% 200 mm cement treated crushed rock (E = 500 MPa)	For subgrade design CBR < 10% 150 mm granular subbase	
	40 mm DGA14 (A35P)	50 mm DGA14 (A35P)	X mm DGA20 (C320), minimum thickness 85 mm	For subgrade design CBR < 10% 150 mm cement treated crushed rock (E = 500 MPa) For subgrade design CBR ≥ 10% 200 mm cement treated crushed rock (E = 500 MPa)	For subgrade design CBR < 10% 150 mm granular subbase	
4 OGA10 surface	30 mm OGA10	40 mm DGA14 (C320)	50 mm DGA14 (C320)	X mm DGA20 (C320), minimum thickness 85 mm	For subgrade design CBR < 10% 150 mm cement treated crushed rock (E = 500 MPa) For subgrade design CBR ≥ 10% 200 mm cement treated crushed rock (E = 500 MPa)	For subgrade design CBR < 10% 150 mm granular subbase
	30 mm OGA10	40 mm DGA14 (A15E)	50 mm DGA14 (A15E)	X mm DGA20 (C320), minimum thickness 85 mm	For subgrade design CBR < 10% 150 mm cement treated crushed rock (E = 500 MPa) For subgrade design CBR ≥ 10% 200 mm cement treated crushed rock (E = 500 MPa)	For subgrade design CBR < 10% 150 mm granular subbase

Pavement and surface type	Layer 1 (surface)	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
	30 mm OGA10	40 mm DGA14 (A35P)	50 mm DGA14 (A35P)	X mm DGA20 (C320), minimum thickness 85 mm	For subgrade design CBR < 10% 150 mm cement treated crushed rock (E = 500 MPa) For subgrade design CBR ≥ 10% 200 mm cement treated crushed rock (E = 500 MPa)	For subgrade design CBR < 10% 150 mm granular subbase

Table 3.5: Pavement Type 5 and 6 configurations

Pavement type	Asphalt surface	Layer 1	Layer 2	Layer 3
5	nil	X mm plain concrete base (undowelled, with tied concrete shoulders)	150 mm lean concrete subbase	200 mm granular subbase
6	nil	X mm continuously reinforced concrete base (with tied concrete shoulders)	150 mm lean concrete subbase	200 mm granular subbase
6a	30 mm open graded asphalt	X mm continuously reinforced concrete base (with tied concrete shoulders)	150 mm lean concrete subbase	200 mm granular subbase

3.3 Regions and Climates

Four regions in Western Australia covering a wide range of temperature climates were chosen for the investigation as detailed in Table 3.6. Costing unit rates were also estimated for these regions (Section 4.1, Section 6.1).

Table 3.6: Regions and climates

Region	Weighted mean annual pavement temperatures (WMAPT)
Bunbury	25 °C
Perth	29 °C
Port Hedland	32 °C
Broome	40 °C

3.4 Design Traffic Loading

ERN9 (Main Roads WA 2012) specifies that fatigue and erosion damage of concrete pavements, fatigue of full depth asphalt pavements and the permanent deformation of flexible pavements must be designed for a 40 year period. In addition, fatigue of thin asphalt wearing courses on crushed rock base or HCTCRB must also be designed for a 15 year period.

Pavement designs were calculated for six levels of 40 year design traffic loading covering a wide range of traffic loadings as indicated in Table 3.7. For pavements with thin asphalt surfacings (Pavement Types 1a, 1b, 1c and 1d), pavements are also designed for an asphalt surfacing fatigue life of 15 years. Assuming a heavy vehicle traffic compound growth rate of 3%, the 15 year design traffic loadings were obtained by multiplying the 40 year values by 0.247. For Pavement Type 1a5, (applicable only to Perth region for well-drained sand subgrade), pavements were also designed for an asphalt surfacing fatigue life of 5 years as a result of objective evidence that this pavement type in Perth exceeds the design life predicted by the Austroads design procedure.

Table 3.7: Design traffic loading

Level	Design traffic loading (ESA)		
	5 years[1]	15 years[2]	40 years
1	7.0×10^4	2.5×10^5	10^6
2	2.1×10^5	7.4×10^5	3×10^6
3	7.0×10^5	2.5×10^6	10^7
4	2.1×10^6	7.4×10^6	3×10^7
5	7.0×10^6	2.5×10^7	10^8
6	2.1×10^7	7.4×10^7	3×10^8

Notes

5 year period used for fatigue life of thin asphalt surfacings Pavement Types 1a5.

15 year period used for fatigue life of thin asphalt surfacings, Pavement Types 1a, 1b, 1c and 1d.

The traffic load distribution assumed in the calculations is given in Appendix A (Kwinana Fwy, Mandurah WIM site 50164) from which the following parameters for estimating standard axle repetitions were calculated:

- SAR5/ESA = 1.25
- SAR7/ESA = 2.08
- SAR12/ESA = 9.85.

For the thickness design of concrete pavements, the cumulative ESA of traffic loadings in Table 3.7 were converted to cumulative heavy vehicle axle groups (HVAG) using an ESA/HVAG factor of = 1.03 (see Appendix A). The axle load distribution used has 31% of the twin steer axles (tandem axles with single tyres) at or above the legal axle load limit (11 tonne). Such a high percentage is not commonly observed in other Australian states. This high percentage of twin steer axles increased the calculated concrete base thicknesses compared to those currently constructed in the eastern states.

3.5 Subgrade Design CBRs

Pavement designs were calculated for the following subgrade design CBRs: 3%, 4%, 5%, 7%, 10%, 12% and 15%.

3.6 Heavy Vehicle Design Speed

Flexible pavements were designed for the representative heavy vehicle design speeds given in Table 3.8.

Table 3.8: Representative heavy vehicle design speeds

Surface type	Representative heavy vehicle design speed (km/h)
30 mm DGA10	50 and 70
40 mm DGA14 intersection mix	10, 50, 70 and 80
30 mm OGA	70, 90 and 100

3.7 Example Results

Due to the very large number of pavements designed it is not practical to detail all of them in this report. Consequently, this section presents design examples to illustrate the outcomes of the design process.

3.7.1 Thin Asphalt Surfaced on Crushed Rock Base (Types 1a, 1a5)

Figure 3.1: and Figure 3.2 show examples of asphalt surfaced crushed rock base pavements for subgrade design CBR of 3% and 12% and a heavy vehicle design speed of 50 km/h, commonly used for urban arterial roads. Note that Pavement Type 1a5, designed using a 5 year asphalt fatigue life, only applies to sand subgrades (CBR = 12) with crushed limestone subbase and crushed rock base in the Perth region.

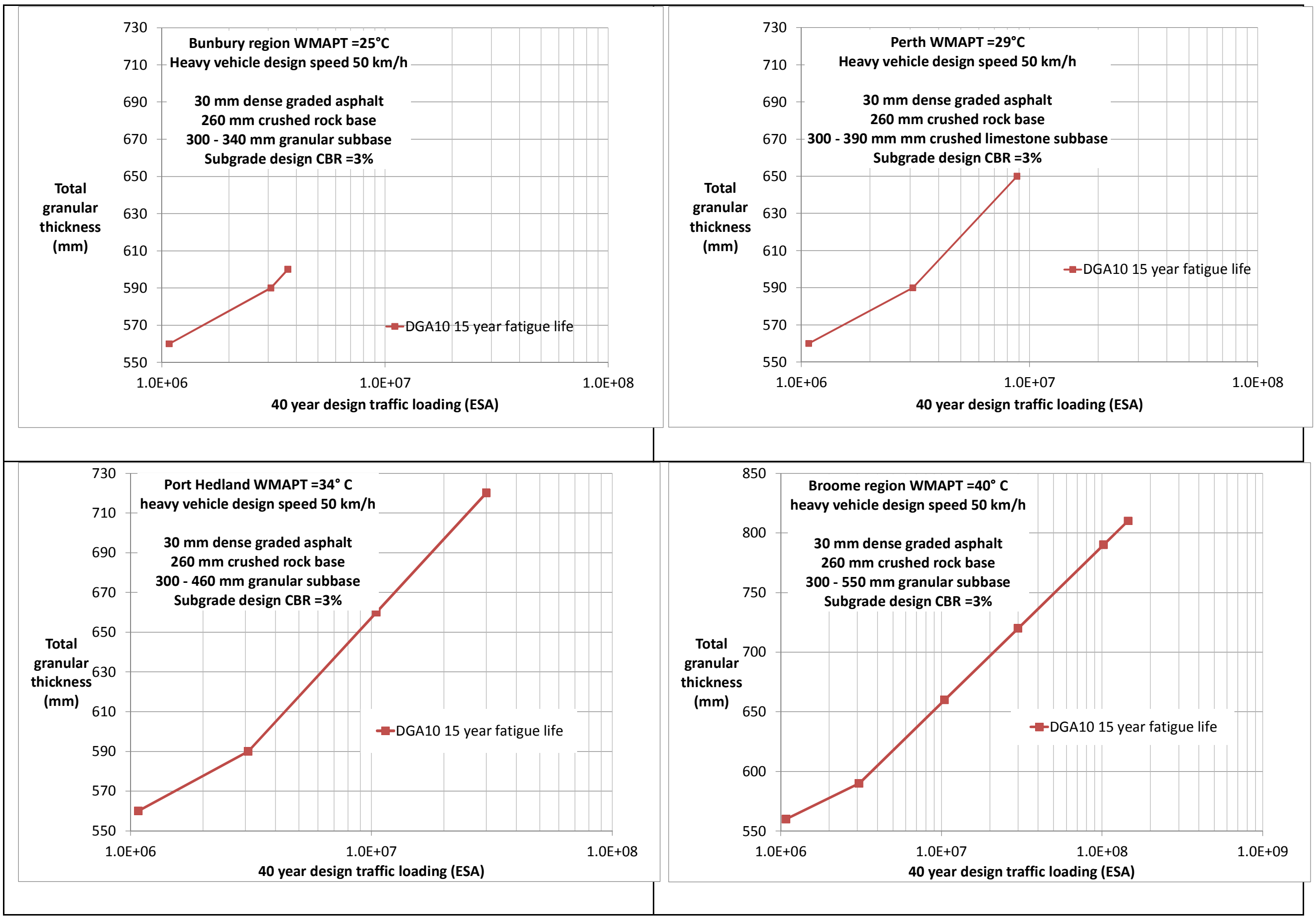

Figure 3.1: Thin asphalt on crushed rock base pavements with surfacing of size 10 mm DGA, subgrade design CBR = 3% and heavy vehicle design speed 50 km/h

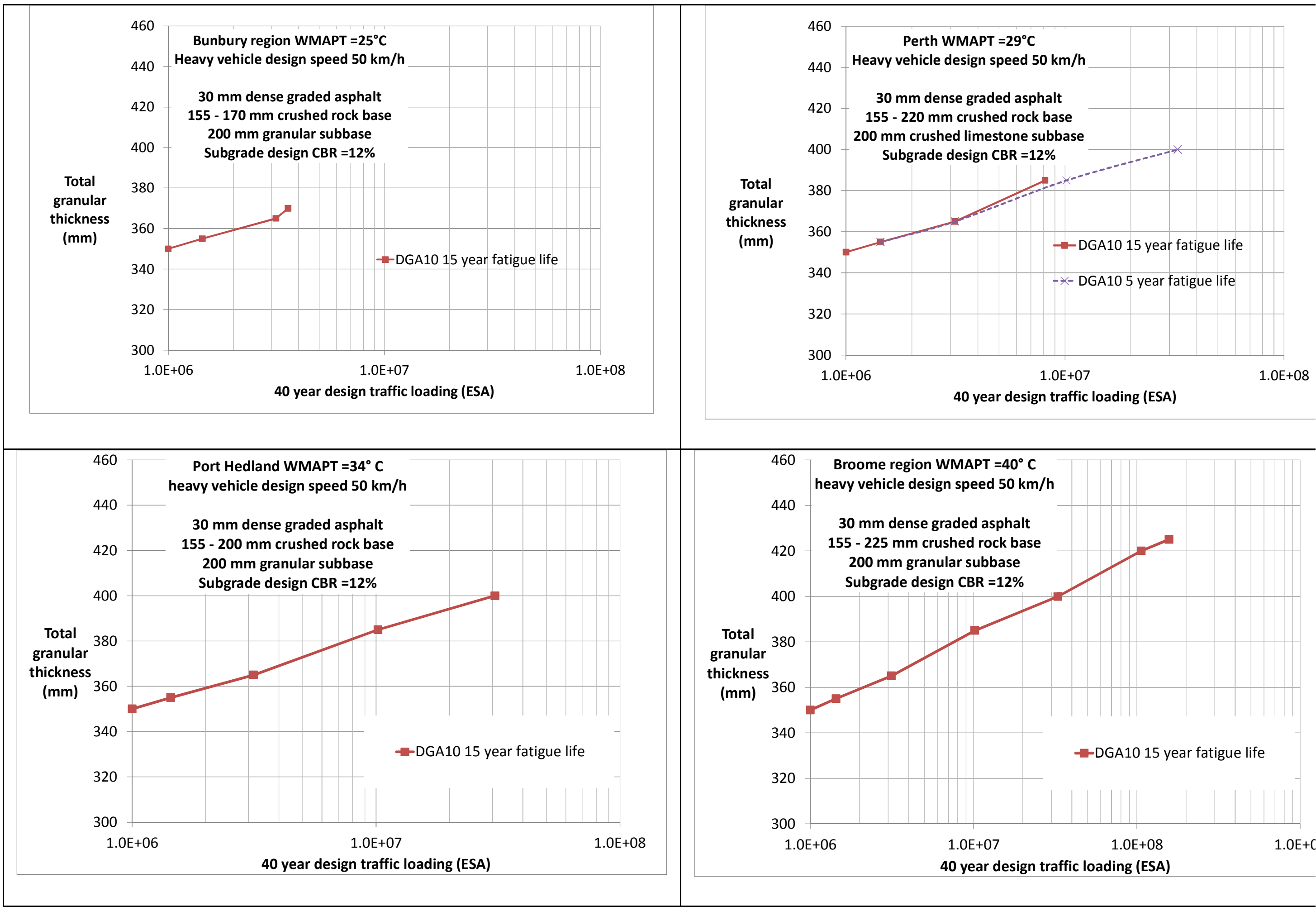

Figure 3.2: Thin asphalt on crushed rock base pavements with surfacing of size 10 mm DGA, subgrade design CBR = 12% and heavy vehicle design speed 50 km/h

It is apparent from Figure 3.1 and Figure 3.2 that the maximum allowable traffic loadings for thin asphalt surfaced CRB pavements increases with the pavement temperature (WMAPT).

As seen from Figure 3.2, for the pavement with a subgrade design CBR of 12% in the Perth region, the use of the 15 year asphalt life design criteria limits the allowable loading to about 8 x 10^6 ESA over 40 years. Main Roads WA experience is that satisfactory asphalt fatigue performance has been observed at higher traffic loadings. Accordingly, at Main Roads WA request the project investigated the effect of reducing the design criteria to a 5 year asphalt fatigue life. This increased the maximum allowable loading to about 3 x 10^7 ESA over 40 years, which is more in line with Main Roads WA experience.

3.7.2 Thin Asphalt Surfaced on HCTCRB (Types 1b, 1c, 1d)

Figure 3.3 shows Perth region design examples for asphalt surfaced HCTCRB pavements for subgrade design of 12% (sand) and heavy vehicle design speed of 90 km/h. The surfacing comprises 30 mm open graded asphalt on 30 mm dense graded asphalt, a surface suitable for Perth freeways.

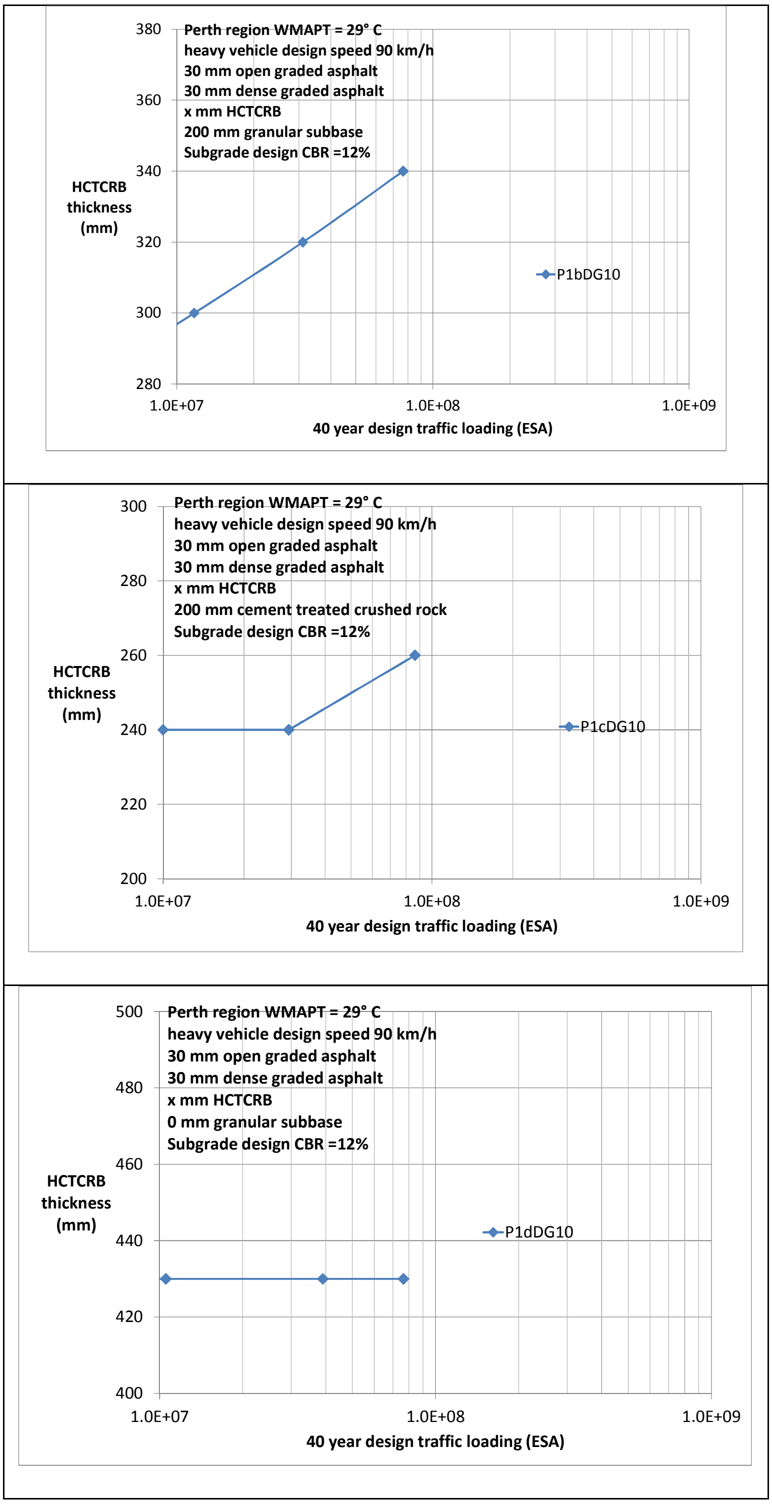

Figure 3.3: Perth region thin asphalt surfaced HCTCRB pavements (Types 1b, 1c and 1d) with open graded asphalt surfacing, design speed 90 km/h and subgrade design CBR = 12%

As seen from Figure 3.3, two alternative HCTCRB pavement types (P1b and P1d) have similar maximum allowable traffic loadings, about a 40 year design traffic loading of 8 x 10^7 ESA.

Note that HCTCRB pavement designs were prepared for regions outside the Perth metropolitan area even though HCTCRB has yet to be manufactured and used in these regions.

For the full-depth HCTCRB pavements (P1d) the thickness of HCTCRB is 430 mm for all design traffic loadings for subgrade design CBR of 12%. As Main Roads WA currently has no field experience with this pavement design, Main Roads WA used a conservative approach in the design by adopting a minimum 230 mm thickness of basecourse with the following minimum subbase requirements:

- subgrade design CBR less than 10%: 150 mm thickness of HCTCRB used as subbase on 150 mm granular subbase
- subgrade design CBR of 10% or more: 200 mm thickness of HCTCRB used as subbase.

These minimum thickness requirements result in a minimum 430 mm thickness of HCTCRB for subgrade design CBR of 12% as shown in Figure 3.3.

3.7.3 Thick Asphalt Pavements

Figure 3.4 to Figure 3.6 show Perth region freeway examples of open graded asphalt surfaced full-depth asphalt, flexible composite and deep strength asphalt designs for subgrade design CBR of 12% and heavy vehicle design speed of 90 km/h.

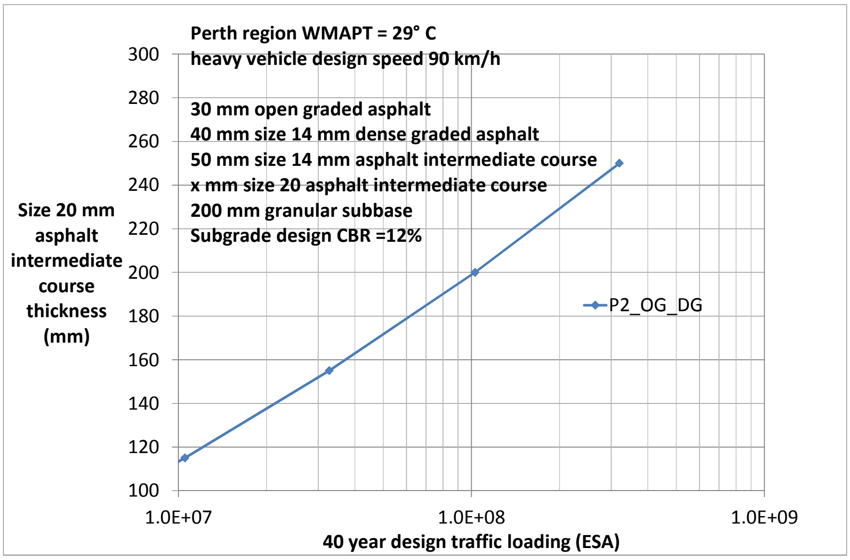

Figure 3.4: Full-depth asphalt design (Type 2) examples for the Perth region, design speed 90 km/h and subgrade design CBR = 12%

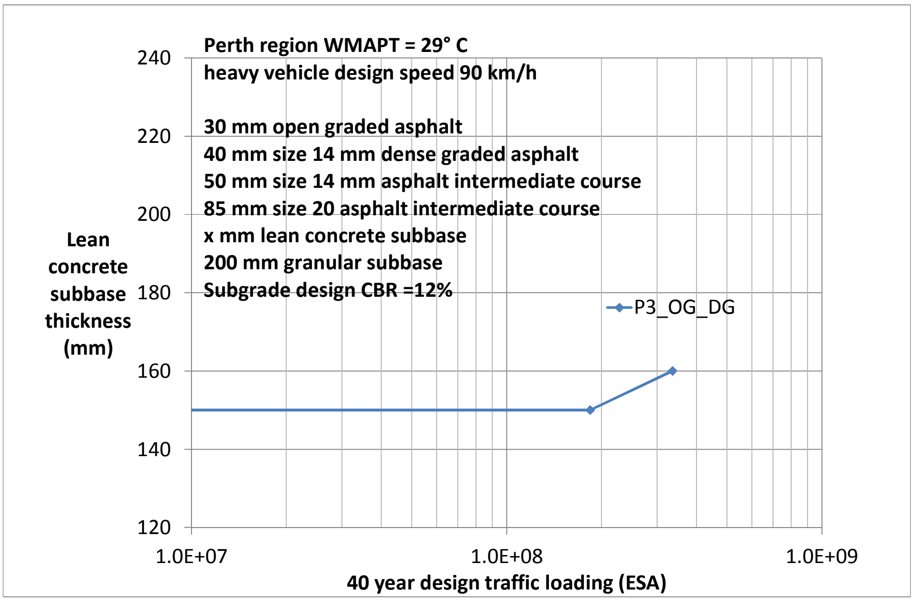

Figure 3.5: Flexible composite (Type 3) design examples for the Perth region, design speed 90 km/h and subgrade design CBR = 12%

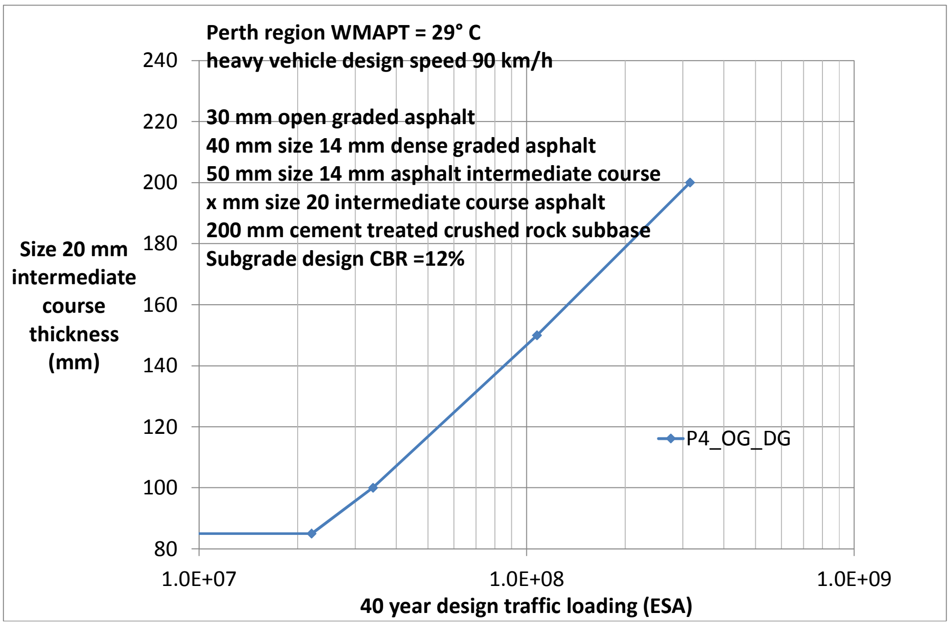

Figure 3.6: Deep strength asphalt (Type 4) design examples for the Perth region, design speed 90 km/h and subgrade design CBR = 12%

3.7.4 Concrete Pavements

The required thickness of concrete base for PCP and CRCP pavements was the same for all temperature regions and for all subgrade design CBRs due to the use of a 150 mm thick lean concrete subbase which provided an effective subgrade strength of 75% (Austroads 2012) in all cases. Note that for Pavement Type 6a, which is CRCP with an open graded asphalt, the concrete base thicknesses are the same as for CRCP without the open graded asphalt.

The concrete base thicknesses (Figure 3.7) are high compared to those used in New South Wales due to the high proportion (31%) of tandem axles with single tyres (TAST, twin steers) loaded to axle load limit (11 tonnes).

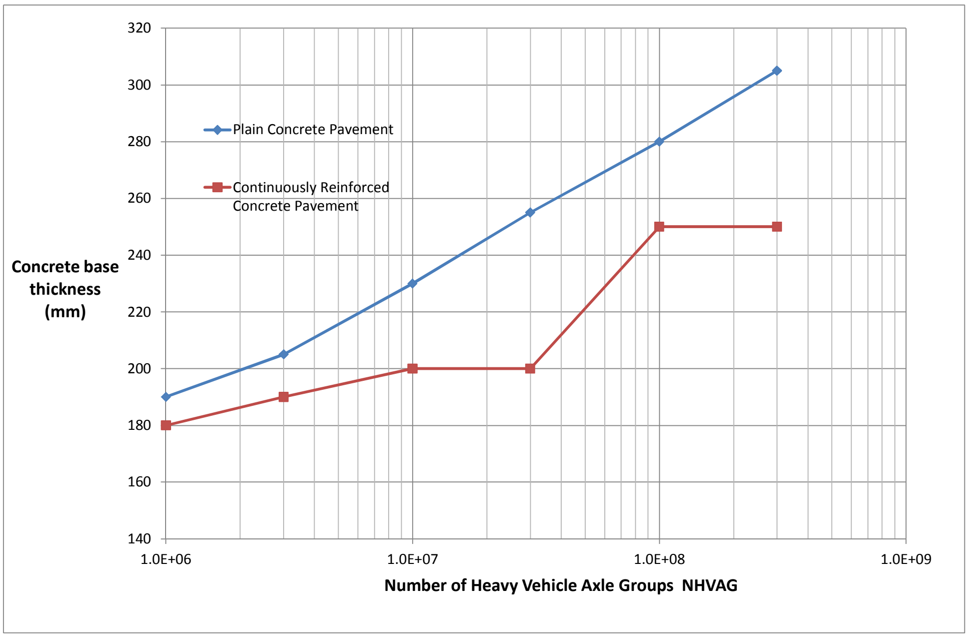

Figure 3.7: Concrete pavement designs (Types 5, 6 and 6a)

4 CONSTRUCTION COSTS

4.1 Unit Rates

Unit cost rates are required to estimate the initial construction costs from the pavement designs. These rates were supplied by Main Roads WA for three scales of works: small, medium and large and for four regions: Bunbury, Perth, Port Hedland and Broome. The unit rates are based on 2012 prices for each region. Where prices were not available, estimates were calculated from first principles and include allowance for extra transport and labour costs in rural regions. Table 4.1 lists the rates used for Perth region, the rates for the other regions are listed in Appendix C .

Table 4.1: Unit rates adopted for the Perth region

Pavement layer / treatment	Unit	Unit rate ($)		
		Small-scale	Medium-scale	Large-scale
Flexible pavements				
Size 10 mm OGA (C320 binder), 30 mm thickness	m^2	15.16	14.36	14.28
Size 10 mm DGA (C170 binder), 30 mm thickness	m^2	15.16	14.36	14.28
Size 10 mm DGA (A15E binder), 30 mm thickness	m^2	17.37	16.57	16.50
Size 14 mm DGA (C320 binder), 40 mm thickness	m^2	19.92	19.12	19.04
Size 14 mm DGA (A15E or A35P binder), 40 mm thickness	m^2	22.59	21.79	21.71
Size 14 mm DGA (C320 binder), 50 mm thickness	m^2	24.67	23.88	23.80
Size 14 mm DGA (A15E or A35P binder), 50 mm thickness	m^2	28.01	27.22	27.14
Geotextile reinforced seal (GRS), 2 coat 14 mm / 7 mm	m^2	15.08	9.62	9.52
Single coat, 10 mm seal (C170)	m^2	4.69	3.90	3.82
Prime coat	m^2	1.13	1.13	1.13
2-coat emulsion seal, 10 mm / 5 mm	m^2	8.50	7.71	7.63
Tack coat	m^2	1.13	1.13	1.13
Size 14 mm, DGA (C320 binder)	m^3	493	478	476
Size 20 mm, DGA (C320 binder)	m^3	493	478	476
Crushed rock base (CRB)	m^3	109	104	104
Hydrated cement-treated crushed rock base (HCTCRB)	m^3	163	159	158
Crushed limestone subbase	m^3	103	99	99
Gravel subbase	m^3	50	45	45
2% cement-treated crushed rock subbase	m^3	171	167	167
Lean concrete subbase (screened wet), including bitumen emulsion seal for curing / bonding	m^3	767	760	759
Concrete pavements				
Jointed plain concrete base, including supply, placement, curing, texturing, joint seals	m^3	675.60	668.57	667.85
Continuously reinforced concrete base, including supply, placement concrete & steel, curing & texturing	m^3	891.52	884.49	883.78
Lean concrete subbase, 5 MPa, subbase slip-formed, curing & debonding	m^3	690.37	608.04	531.54
Size 10 mm OGA (C320 binder), 30 mm thickness	m^2	15.16	14.36	14.28
Prime coat	m^2	1.13	1.13	1.13
10 mm PMB seal	m^2	7.24	6.44	6.36

All unit rates relating to concrete pavement items were estimated from first principles due to concrete pavements not generally being constructed in Western Australia. The estimated unit rates are higher than typical costs experienced in New South Wales where a concrete pavement industry is well established. Unit rates for Western Australia could be expected to decrease if there was sufficient demand to sustain a concrete pavements industry.

4.2 Initial Construction Costs

In all, initial construction costs were calculated for about 25 000 designs. A WOLCC Calculator was developed and supplied to Main Roads WA to enable cost comparisons of alternative pavement types.

To illustrate the results, Figure 4.1 depicts some examples of costs for Perth region; example costs for Bunbury, Port Hedland and Broome regions are listed in Appendix D.

4.2.1 Perth Freeways

Figure 4.1 and Figure 4.2 are examples of the initial construction costs for Perth freeways based on unit rates for large-scale works. The surfacing comprises an open graded asphalt wearing course with:

- 30 mm thick size 10 dense graded asphalt with C170 bitumen on granular pavements (P1a, P1a5, P1b, P1c, P1d); or
- 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen on full-depth asphalt, flexible composite or deep strength asphalt pavement (P2, P3 and P4); or
- continuously reinforced concrete base (P6a).

As expected for the more lightly-loaded freeways (< 8×10^7 ESA), thin asphalt surfaced HCTCRB pavements are clearly the lowest in cost. For the common case of a subgrade design CBR of 12%, Figure 4.2 indicates that HCTCRB on crushed limestone subbase (P1b) and full-depth HCTCRB (P1d) pavements have similar costs and maximum design traffic loadings.

For freeways where the 40 year design traffic loading exceeds the maximum allowable loading (about 8×10^7 ESA) of thin asphalt surfaced HCTCRB pavements, the full-depth asphalt pavements (P2) or deep strength asphalt pavements (P4) are the lowest cost options.

4.2.2 Perth Arterial Roads

Figure 4.3 and Figure 4.4 are examples of the initial construction costs for Perth arterial roads based on unit rates for medium-scale works. Except for the concrete pavement options (which have no wearing course), the wearing course was either:

- 30 mm thick size 10 dense graded asphalt with C170 bitumen on granular pavements (P1a, P1a5, P1b, P1c, P1d); or
- 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen on full-depth asphalt, flexible composite or deep strength asphalt pavement (P2, P3 and P4).

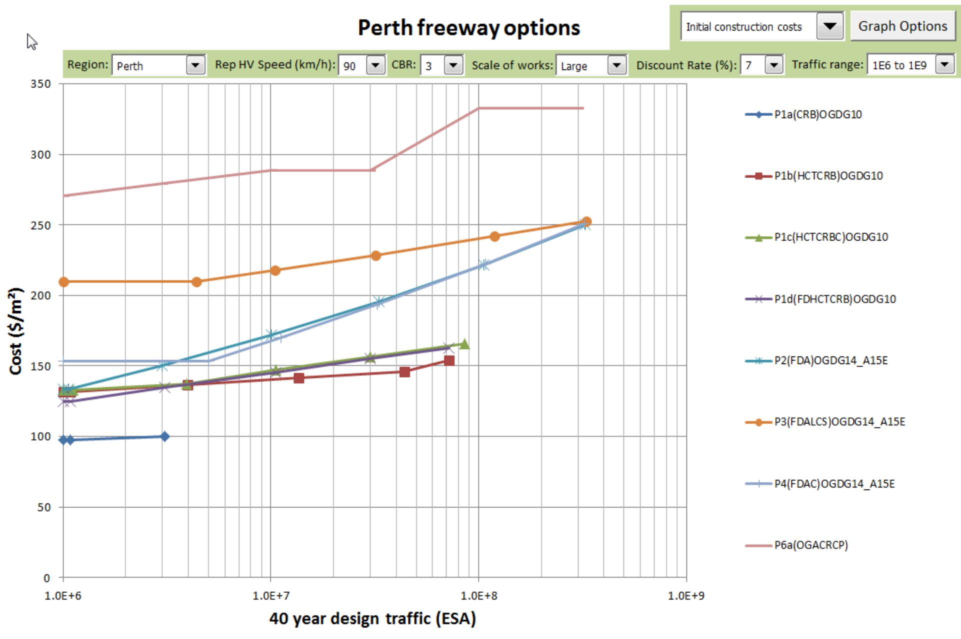

Figure 4.1: Initial construction costs for Perth region freeways with open graded asphalt surfacing, subgrade design CBR = 3% and design speed 90 km/h

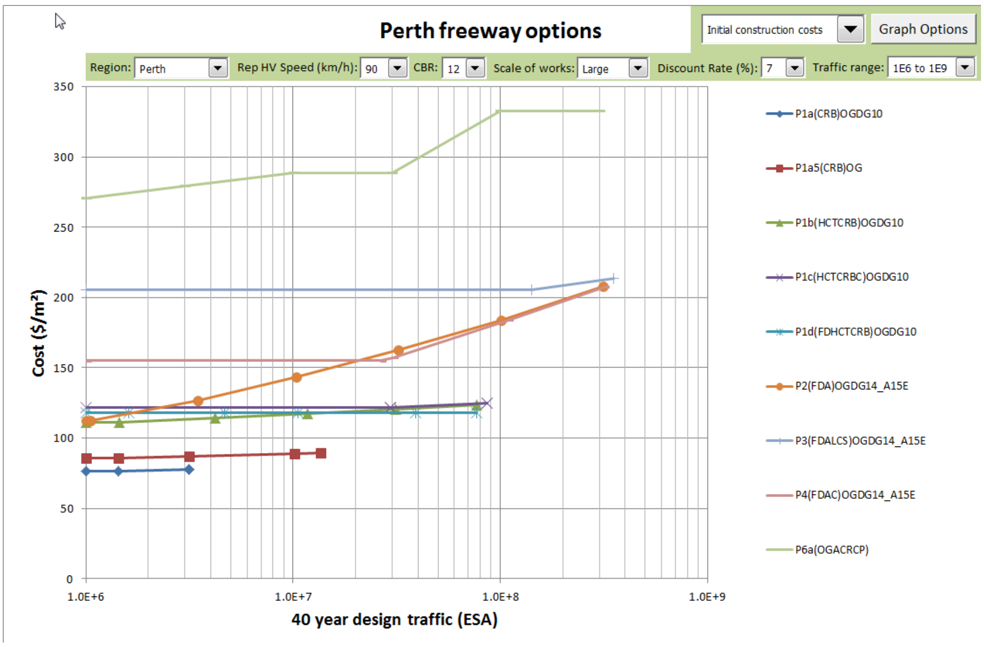

Figure 4.2: Initial construction costs for Perth region freeways with open graded asphalt surfacing, subgrade design CBR = 12% and design speed 90 km/h

As part of the project, Main Roads WA requested evaluation of Pavement Type 1a5, thin asphalt surfaced crushed rock base pavement designed with a 5 year asphalt fatigue life rather than the current practice of specifying a 15 year fatigue life. Figure 4.3 and Figure 4.4 indicate that asphalt on crushed rock base (Types P1a and P1a5) have the lowest construction cost for Perth arterial roads. For commonly used subgrade design CBR of 12% (sand), the maximum allowable traffic loading over 40 years of thin asphalt surface granular pavements with 5 year fatigue life (P1a5) is about 3 x 10^7 ESA. For more heavily trafficked arterials, thin asphalt on full-depth HCTCRB pavements (P1d) have the lowest cost.

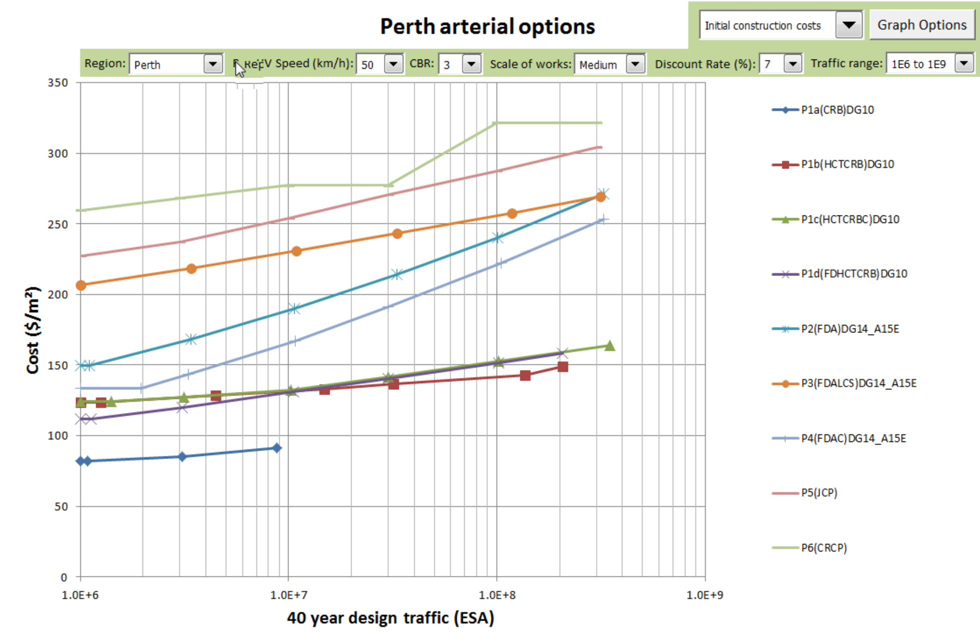

Figure 4.3: Initial construction costs for Perth region arterial roads with dense graded asphalt surfacing, subgrade design CBR = 3% and design speed 50 km/h

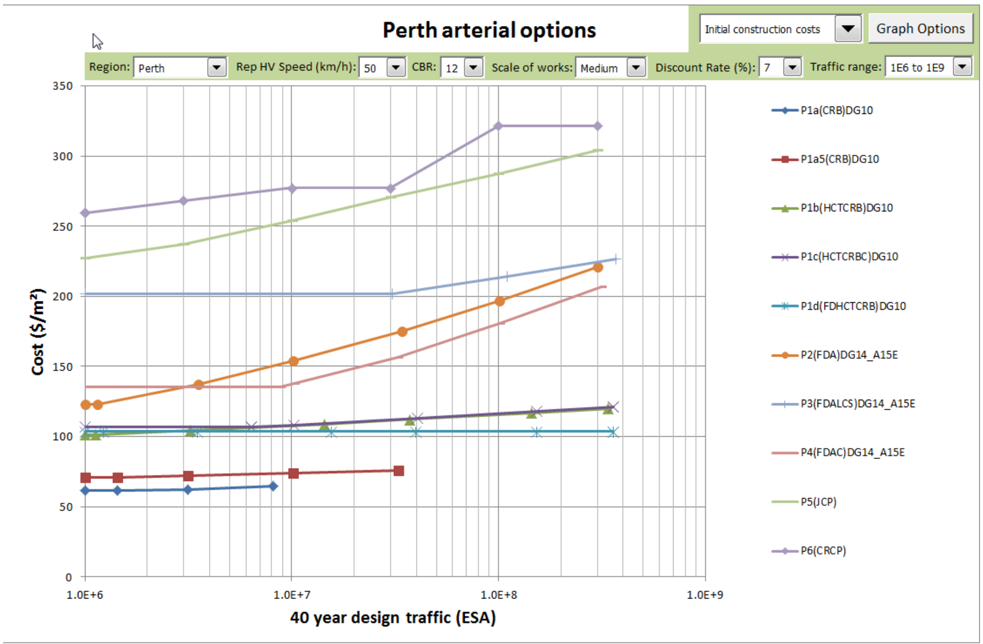

Figure 4.4: Initial construction costs for Perth region arterial roads with dense graded asphalt surfacing, subgrade design CBR = 12% and design speed 50 km/h

4.2.3 Perth Signalised Intersections

In calculating the pavement designs at signalised intersections, Main Roads WA design manual (ERN9) requires the use of different heavy vehicle design speeds in calculating asphalt moduli depending on pavement type:

- For pavements with a total asphalt thickness more than 60 mm (e.g. full-depth asphalt), a heavy vehicle design speed of 10 km/h is used.
- For pavements with a total asphalt thickness 60 mm or less, 10 km/h less than the posted speed limit is used.

In each case this is a conservative design assumption.

Figure 4.5 and Figure 4.6 are examples of the construction costs for Perth intersections based on unit rates for small-scale works and heavy vehicle design speed of 50 km/h for thin asphalt surfaced granular base pavements and 10 km/h for other pavement types. Except for the concrete pavement options, the wearing course is 40 mm thickness of size 14 dense graded asphalt using A15E polymer modified C320 bitumen. Note that designs are not provided for HCTCRB pavements as the inclusion of the geotextile reinforced seal to reduce the risk of reflection cracking results in this pavement type being unsuitable for the high shear stresses at signalised intersections.

Figure 4.5 and Figure 4.6 indicate that at lightly trafficked intersections thin asphalt surfaced crushed rock base pavements (P1a and P1a5) have the lowest construction costs. Note that although the Main Roads WA design manual (ERN 9) requires the use of polymer modified binder A15E at intersections for rut-resistance, no allowance is made for the calculated increase in fatigue life due to its lower modulus. For a commonly used subgrade design CBR of 12% (sand), the maximum allowable traffic loading over 40 years of thin asphalt surface granular pavements with 5 year fatigue life (P1a5) is about 8 x 10^6 ESA. As most signalised intersections have 40 year design traffic loading greater than 10^7 ESA, generally thick asphalt on cement treated crushed rock subbase pavements (P4) have the lowest cost.

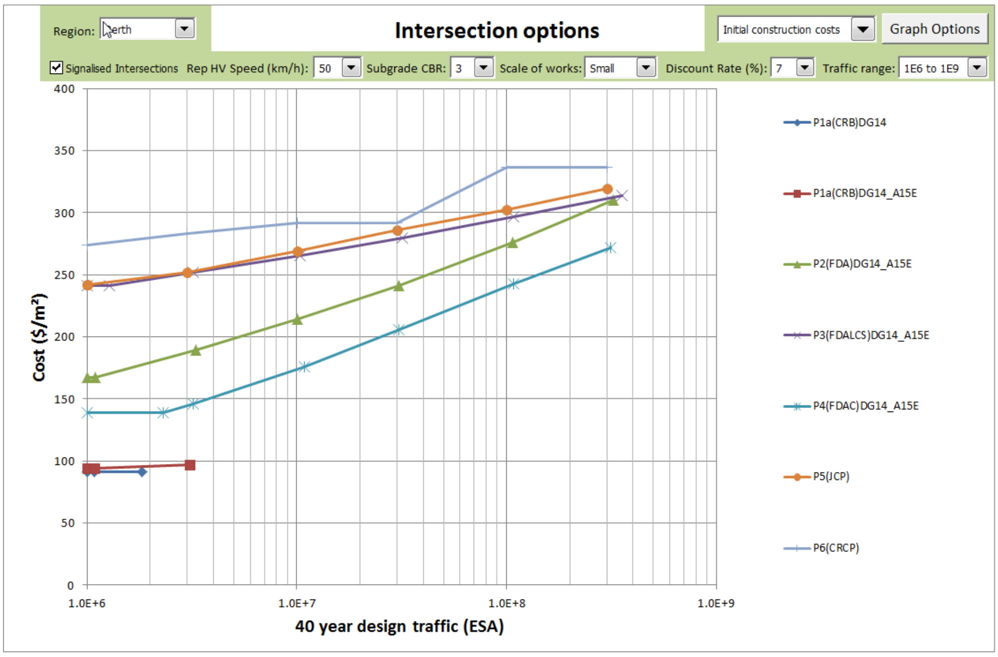

Figure 4.5: Initial construction costs for Perth region signalised intersections, subgrade design CBR = 3%

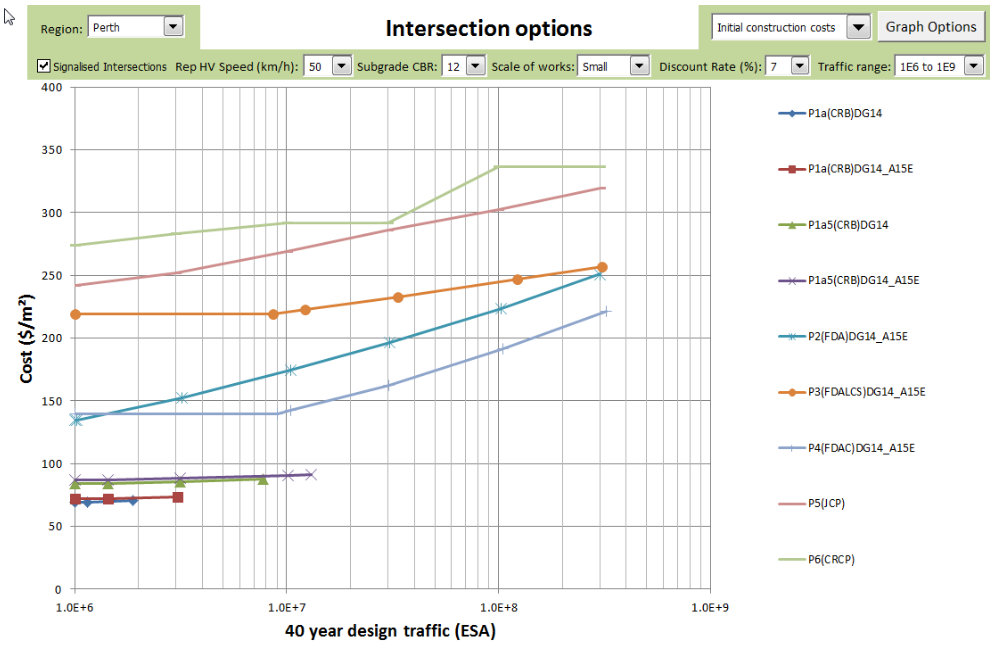

Figure 4.6: Initial construction costs for Perth region signalised intersections, subgrade design CBR = 12%

4.3 Bunbury, Port Hedland and Broome Regions Costs

Examples of initial construction costs for Bunbury, Port Hedland and Broome regions are listed in Appendix D.

The common regional application of asphalt surfaced and concrete designs are at signalised intersections for which a sprayed seal surface has inadequate shear resistance. Figure 4.7, Figure 4.8 and Figure 4.9 illustrate the initial costs for a subgrade design CBR=12%.

For Bunbury and Port Hedland regions, except for very lightly-trafficked projects (< 10^7 ESA), thick asphalt on cement treated crushed rock subbase (P4) is the lowest cost.

For Broome the thin asphalt surfaced granular pavements are the lowest case up to about 2 x 10^7 ESA beyond which they have inadequate fatigue life> For higher loadings once again deep strength asphalt pavements (P4) are the lowest in initial cost.

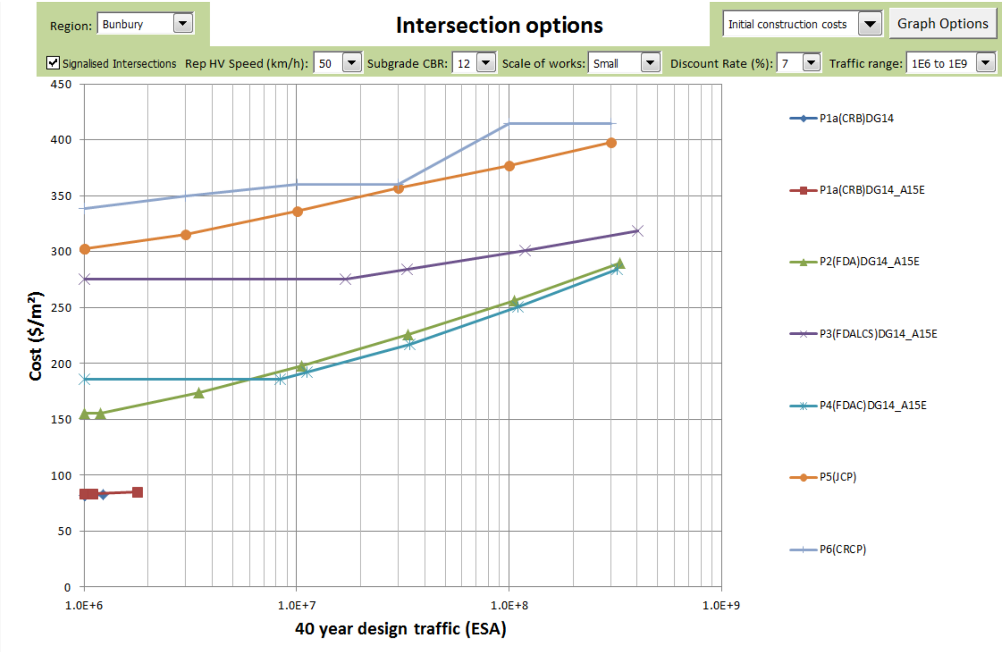

Figure 4.7: Initial construction costs for Bunbury region signalised intersections, dense graded asphalt surfacing, subgrade design CBR = 12%

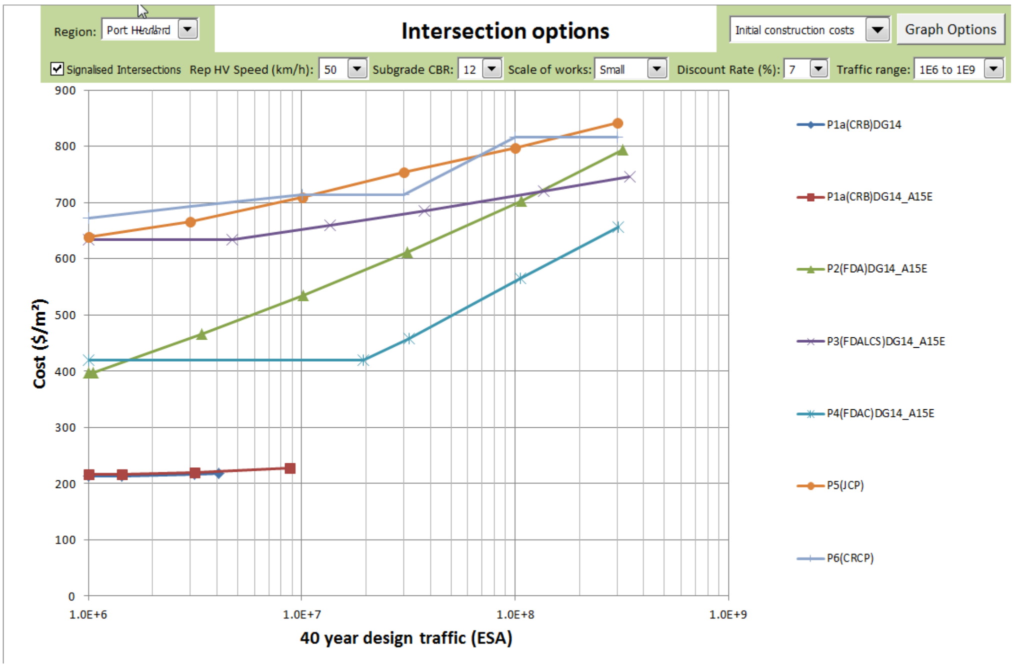

Figure 4.8: Initial construction costs for Port Hedland region signalised intersections with dense graded asphalt surfacing, subgrade design CBR = 12%

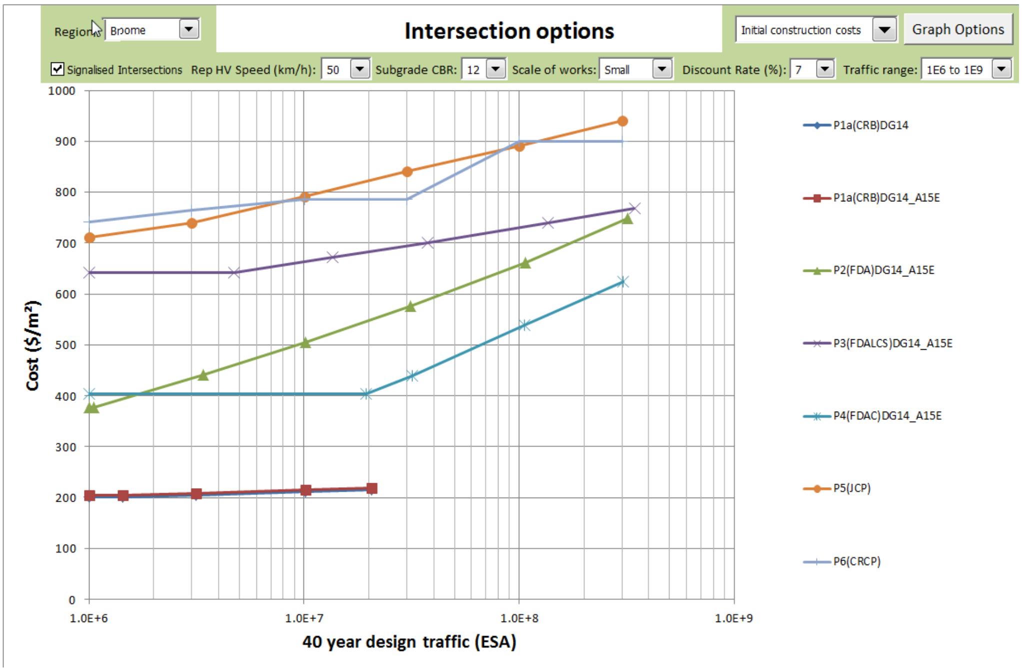

Figure 4.9: Initial construction costs for Broome region signalised intersections with dense graded asphalt surfacing, subgrade design CBR = 12%

5 MAINTENANCE SCENARIOS

5.1 Introduction

To calculate the WOLCC it is necessary to determine the maintenance requirements of the alternative pavement types.

Webb et al. (2012) detail the initial development of the maintenance treatments, later refined in consultation with Main Roads WA. The maintenance requirements for all pavement types were not readily available despite extensive consultations with state road agencies and literature reviews. As a result, a number of assumptions were made in order to compile maintenance scenarios for the various pavement types. Assumptions about the distribution (timing of interventions) of pavement maintenance and rehabilitation activities, and the extent (quantity of the intervention) as presented in the maintenance scenarios, have been largely drawn from the responses received from other road agencies and represent the professional judgement of experienced road engineers.

Main Roads WA has considerable experience in the maintenance requirements of Pavement Type 1a, thin asphalt surfaced crushed rock base pavements and Pavement Type 1a5 (Type 1a with a 5 year asphalt surfacing fatigue life, and with a limestone sub-base on sand subgrade). Consequently, the maintenance scenarios were developed in conjunction with Main Roads WA staff and largely reflect current Main Roads WA maintenance practices. Main Roads WA also provided guidance on the scenarios for, application to thin asphalt surfaced crushed rock base pavements constructed on sand subgrades in the Perth metropolitan area.

Pavement Types 1b, 1c and 1d, which incorporate thin asphalt layers over a HCTCRB basecourse, are only constructed in Western Australia and no performance history or maintenance information was available from any other jurisdiction. Hence, maintenance scenarios for this pavement type were also developed in consultation with Main Roads WA staff.

Main Roads WA has limited experience in the maintenance requirements of thick asphalt pavements and concrete pavement types. Consequently, the proposed scenarios were developed from the experience of the eastern states as detailed in Webb et al. (2012). The maintenance scenarios for surfacing replacement of the open graded asphalt options for thick asphalt Pavement Types 2, 3 and 4 were also adopted for the granular Pavement Types 1a to 1d, in order to maintain consistency. This is a conservative approach compared to Main Roads WA experience of not replacing the underlying dense graded asphalt at the first open graded asphalt replacement.

The scope of this project was whole-of-life-cycle costing over a wide range of Western Australian climates, traffic loadings and traffic speeds. As there was insufficient information available to develop separate scenarios for each situation, the scenarios listed were used for all situations.

The analysis included pavements with polymer modified binder in the upper asphalt layers. There was insufficient information to develop different maintenance scenarios for pavements with these asphalt mixes. As it is anticipated that the use of the polymer modified binder would increase the interval between surfacing treatments, the discounted maintenance costs for these pavements may be over-estimated.

When conducting WOLCC analyses with different maintenance treatments at different times over the analysis period, it is normal to also introduce sensitivity alternatives to the base case, commonly in the form of optimistic case and pessimistic case maintenance treatments. However, when the findings of Webb et al. (2012) were discussed with Main Roads WA it was agreed that the WOLCC should only consider the base case given the large quantity of data to be analysed.

The following sections describe the maintenance treatments used to estimate the discounted maintenance costs over the 40 year analysis period.

5.2 Pavement Type 1a

This pavement comprises thin asphalt surfacing on crushed rock base (CRB) with granular subbase. It is commonly used for moderately-trafficked arterial roads.

Main Roads WA has extensive experience with this pavement type, particularly in the Perth region. Although these pavements are designed to have a 15 year (Pavement Type 1a) asphalt fatigue life and a 40 year structural rutting life, Main Roads WA experience is that these pavements would generally not need to be reconstructed within the 40 year analysis period. Periodic resurfacings plus routine maintenance are sufficient to provide a serviceable pavement.

The adopted maintenance treatments and timings are given in Table 5.1 for the various surfacing types. Note that the surfacing life at intersections is lower due to the additional stresses applied by turning and braking traffic. There was insufficient information to allow for the differences in maintenance due to the use of polymer modified binders in the surfacings.

Table 5.1: Maintenance scenarios for Pavement Type 1a, asphalt surfaced crushed rock base

Surfacing	Maintenance treatment	Year
DGA10	Mill 30 mm, SAMI, place 30 mm DGA overlay	15, 30
	Heavy patching over 1% area	15, 30
	Routine maintenance	3-15, 18-30, 33-40
	Reconstruction	> 40
DGA14 IM (mid-block)	Mill 40 mm, SAMI, place 40 mm DGA overlay	15, 30
	Heavy patching over 1% area	15, 30
	Routine maintenance	3-15, 18-30, 33-40
	Reconstruction	> 40
DGA14 IM (signalised intersections)	Mill 40 mm, SAMI, place 40 mm DGA overlay	10, 20, 30, 40
	Heavy patching over 1% area	10, 20, 30, 40
	Routine maintenance	3-10, 13-20, 23-30, 33-40
	Reconstruction	> 40
30 mm OGA10 on 30 mm DGA10	Mill 60 mm, SAMI, place 30 mm DGA and 30 mm OGA overlays	11, 22
	Mill 60 mm, geotextile reinforced seal, place 30 mm DGA and 30 mm OGA overlays	33
	Heavy patching over 1% area	11, 22, 33
	Routine maintenance	3-11, 14-22, 25-33, 36-40
	Reconstruction	> 40

5.3 Pavement Type 1a5

This pavement is similar to Pavement Type 1a, except that it is designed with a thin asphalt surfacing fatigue life of 5 years rather than 15 years: it is only applicable to Perth region pavements constructed on limestone sub-base on well drained sand subgrades of CBR=12%. As there is an increased risk of premature fatigue cracking of this pavement type compared to Type 1a, Main Roads WA requested different treatments be considered in the WOLCC to address this risk. Accordingly, for Type 1a5 the initial surfacing treatment includes a two coat 10/5 mm emulsion primerseal and a double 14/7 mm heavy grade fabric geotextile reinforced seal (GRS). Main Roads WA anticipates that the GRS will need be replaced after about 32 years.

Pavement Type 1a5 is commonly constructed across the Perth network without a GRS and Main Roads WA observations are that this pavement type performs well in excess of the design life predicted by the Austroads design procedure. Main Roads WA conservatively anticipates that a resurfacing interval of 8 years (i.e. additional 3 years above the 5 year asphalt fatigue design life due to the effect of the GRS) for all surfacing types.

The maintenance scenarios are given in Table 5.2 for the various surfacing types. There was insufficient information to allow for the differences in maintenance due to the use of polymer modified binders in the surfacings.

Table 5.2: Maintenance scenarios for Pavement Type 1a5, asphalt surfaced crushed rock base

Surfacing	Maintenance treatment	Year
DGA10	Mill 30 mm, SAMI, place 30 mm DGA overlay	8, 16, 24, 40
	Mill 30 mm, place a 14/7 heavy grade fabric geotextile reinforced seal (GRS), place 30 mm DGA overlay	32
	Heavy patching over 1% area	8, 16, 24, 32, 40
	Routine maintenance	3-8, 11-16, 19-24, 27-32, 35-40
	Reconstruction	> 40
DGA14 IM (both mid-block and at signalised intersections)	Mill 40 mm, SAMI, place 40 mm DGA overlay	8, 16, 24, 40
	Mill 40 mm, place a 14/7 heavy grade fabric geotextile reinforced seal (GRS), place 40 mm DGA overlay	32
	Heavy patching over 1% area	8, 16, 24, 32, 40
	Routine maintenance	3-8, 11-16, 19-24, 27-32, 35-40
	Reconstruction	> 40
30 mm OGA10 on 30 mm DGA10	Mill 60 mm, SAMI, place 30 mm DGA and 30 mm OGA overlays	8, 16, 24, 32, 40
	Mill 60 mm, 14/7 heavy grade fabric geotextile reinforced seal (GRS), place 30 mm DGA and 30 mm OGA overlays	32
	Heavy patching over 1% area	8, 16, 24, 32, 40
	Routine maintenance	3-8, 11-16, 19-24, 27-32, 35-40
	Reconstruction	> 40

5.4 Pavement Types 1b, 1c and 1d

These pavement types comprise thin asphalt surfacing on hydrated cement treated crushed rock base (HCTCRB).

The subbase requirements vary:

- Pavement Type 1b has an unbound granular subbase (commonly crushed limestone in Perth region).
- Pavement Type 1c has a cement treated crushed rock subbase.
- Pavement Type 1d is full-depth HCTCRB.

Main Roads WA has tightened HCTCRB design criteria and construction specifications over the last three years to reduce the risk that it develops shrinkage and fatigue cracking. The pavement is now required to include a geotextile reinforced seal (GRS) to reduce the risk that any potential cracking in the HCTCRB will lead to cracking of the overlying asphalt surfacings.

Given the significant changes to this pavement type over the last 3 years, there is limited knowledge about the likely maintenance requirements. One critical issue is the likelihood of the HCTCRB cracking and if so the effectiveness of GRS in delaying the onset of reflection cracking. As GRS has only recently been used in Western Australia, VicRoads experience with this treatment was considered. When cracked cement treated crushed rock base pavements are resurfaced with GRS and thin asphalt overlay, VicRoads' experience is that the treatment has a life of 8 - 10 years. Based on this advice, a conservative resurfacing interval of 8 years was adopted.

Given the performance of Pavement Type 1a, if the HCTCRB pavements are resurfaced in this way, Main Roads WA' judgement is that these pavements would generally not need to be reconstructed within the 40 year analysis period; periodic resurfacings plus routine maintenance will be sufficient to provide a serviceable pavement.

As Main Roads WA have yet to construct Pavement Types 1c and 1d there is no history of their maintenance requirements. Main Roads WA considered it reasonable to assume the same maintenance treatments for Types 1b, 1c and 1d.

The maintenance scenarios are given in Table 5.3 for the various surfacing types. There was insufficient information to allow for the differences in maintenance due to the use of polymer modified binders in the surfacings.

As this pavement type requires a GRS it is not suitable for use at signalised intersections, which are subject to high shear stresses. Consequently, HCTCRB pavements were not included in the analysis for signalised intersections.

Table 5.3: Maintenance scenarios for Pavement Types 1b, 1c and 1d, asphalt surfaced HCTCRB

Surfacing	Maintenance treatment	Year
DGA10	Mill 30 mm, geotextile reinforced seal, 30 mm DGA10 overlay	8, 16, 24, 32, 40
	Heavy patching over 1% area	8, 16, 24, 32, 40
	Routine maintenance	3-8, 11-16, 19-24, 27-32, 35-40
	Reconstruction	> 40
DGA14 (mid-block)	Mill 40 mm, geotextile reinforced seal, 40 mm DGA14 overlay	8, 16, 24, 32, 40
	Heavy patching over 1% area	8, 16, 24, 32, 40
	Routine maintenance	3-8, 11-16, 19-24, 27-32, 35-40
	Reconstruction	> 40
30 mm OGA10 on 30 mm DGA10	Mill 60 mm, geotextile reinforced seal, 30 mm DGA10 and 30 mm OGA overlays	8, 16, 24, 32, 40
	Heavy patching over 1% area	8, 16, 24, 32, 40
	Routine maintenance	3-8, 11-16, 19-24, 27-32, 35-40
	Reconstruction	> 40

5.5 Pavement Types 2, 3 and 4

Webb et al. (2012) detail the development of maintenance scenarios for:

- Pavement Type 2: full-depth asphalt, granular subbase
- Pavement Type 3: flexible composite, comprising a minimum 175 mm thickness of dense graded asphalt, lean concrete subbase (LCS)
- Pavement Type 4: deep strength asphalt (min. 175 mm dense graded asphalt); cement treated crushed rock subbase.

There was insufficient data available to enable development of separate scenarios for each of these pavement types. As Main Roads WA has limited experience with these pavement configurations, the scenarios were developed based on eastern states guidance (Webb et al. 2012).

Table 5.4 shows the maintenance scenarios for Pavement Types 2, 3 and 4.

For pavements surfaced with dense graded asphalt surfacing, the maintenance treatments were based on the examples in the Roads and Maritime Services (RMS) New South Wales *Economic Analysis Manual* (RTA 1999), except that the pavements were assumed not to require reconstruction within the 40 year analysis period. This reflects the conservatism built into the design method (Main Roads WA 2012) when designed for 95% reliability of outlasting the 40 year design period. A resurfacing interval of 15 years was adopted, consistent with the example in the RMS Manual, similar to the Queensland Department of Transport and Main Roads (TMR) advice of 14 years, and a more conservative interval than the VicRoads' advice of 20 years (Webb et al. 2012).

Pavements at intersections are surfaced with size 14 mm dense graded asphalt intersection mix. Despite the use of this more rut-resistant mix it was assumed that the higher stresses due to braking and turning traffic would result in more frequent maintenance than pavement areas without these higher stresses. A resurfacing interval of 10 years was adopted, consistent with VicRoads' experience (Webb et al. 2012).

For pavements with open graded asphalt surfacing, VicRoads experience is that the surfacing lasts 10 to 12 years for heavily trafficked roads, whereas TMR and Department of Planning Transport and Infrastructure South Australia advice is 10 years. It was decided to adopt a surfacing life of 11 years in the analysis.

Table 5.4: Maintenance scenarios for Pavement Types 2, 3 and 4

Surfacing	Maintenance treatment	Year
DGA14 (mid-block)	Mill 40 mm, 40 mm DGA14 overlay	15, 30
	Heavy patching over 1% area	15, 30
	Routine maintenance	3-15, 18-30, 33-40
	Reconstruction	> 40
DGA14 IM (at signalised intersections)	Mill 40 mm, 40 mm DGA14 overlay	10, 20, 30, 40
	Heavy patching over 1% area	10, 20, 30, 40
	Routine maintenance	3-10, 13-20, 23-30, 33-40
	Reconstruction	> 40
30 mm OGA10 on 40 mm DGA14	Mill 60 mm, SAMI, 40 mm DGA14 and 30 mm OGA overlays	11, 22, 33
	Heavy patching over 1% area	11, 22, 33
	Routine maintenance	3-11, 14-22, 25-33, 36-40
	Reconstruction	> 40

5.6 Pavement Types 5, 6 and 6a

Webb et al. (2012) detail the development of maintenance scenarios for:

- Pavement Type 5: plain concrete pavement (PCP)
- Pavement Type 6: continuously reinforced concrete pavement (CRCP).

As Main Roads WA has limited experience with these pavement configurations, the maintenance treatments and intervals were developed from eastern states experience, principally RMS NSW.

For Pavement Type 5 (PCP), the RMS Manual (RTA 1999) provided an example of maintenance scenarios. This was adopted except that the pavement was assumed not to require reconstruction within the 40 year analysis period. This reflects the conservatism built into the Austroads structural design model (Austroads 2012) when designed for 95% reliability of outlasting the design traffic during a 40 year design period.

RMS experience is that Pavement Type 6 (CRCP) requires lower maintenance than PCP. The RMS Manual does not provide an example of maintenance treatments for CRCP; however the survey of RMS practitioners provided an example. Accordingly, the maintenance treatments for CRCP were developed by reducing the structural treatments adopted for PCP and utilising the practitioner's advice (Webb et al. 2012).

For Pavement Type 6a, the maintenance treatments were adapted from those for Pavement Type 6, by deleting the requirement for retexturing of the concrete surface and inclusion of periodic removal and replacement of the open graded asphalt surfacing.

Table 5.5 shows the maintenance scenarios for Pavement Types 5, 6 and 6a.

Table 5.5: Maintenance scenarios for Pavement Types 5, 6 and 6a

Pavement	Maintenance treatment	Year
Type 5 PCP	Concrete slab replacement of 0.5% area	2, 5, 10, 15, 20, 25, 28, 30, 33, 35, 38
	Cross stitch – 20 m/lane-km, 10% of cracks will also require routing, cleaning and sealing	2, 6, 12, 20
	Cross stitch – 40 m/lane-km, 10% of cracks will also require routing, cleaning and sealing	28, 36
	Remove and replace joint seal	10, 20, 30, 40
	Retexture 30% area	20, 40
	Routine maintenance	1-40
	Reconstruction	> 40
Type 6 CRCP	Base replacement of 0.5% area	10
	Base replacement of 1% area	20, 30, 40
	Remove and replace longitudinal joint seal	10, 20, 30, 40
	Retexture 30% area	20, 40
	Routine maintenance	1-40
	Reconstruction	> 40
Type 6a CRCP with OGA surfacing	Mill 30 mm, place PMB seal and 30 mm OGA overlay	10, 20, 30, 40
	Base replacement of 0.5% area	10
	Base replacement of 1% area	20, 30, 40
	Remove and replace longitudinal joint seal	10, 20, 30, 40
	Routine maintenance	1-40
	Reconstruction	> 40

6 MAINTENANCE COSTS

6.1 Unit Rates

Unit cost rates for maintenance are required to estimate the discounted maintenance costs over the 40 year analysis period. The unit rates were supplied by Main Roads WA for three scales of works (small, medium and large) and four regions (Bunbury, Perth, Port Hedland and Broome). The unit rates are based on 2012 prices for each region. Where prices were not available, estimates were calculated from first principles and include allowance for extra transport and labour costs in rural regions. Table 6.1 lists the flexible pavement unit rates for Perth region; the rates for all four regions are listed in Appendix C.2.

Note that the unit rates for medium and large-scale works were similar.

Table 6.1: Flexible pavement maintenance costs adopted for the Perth region

Pavement layer / treatment	Unit	Unit rate ($)		
		Small-scale	Medium-scale	Large-scale
Maintenance flexible pavements				
Mill 30 mm	m^2	5.73	5.47	5.44
Pave 30 mm OGA	m^2	15.16	14.36	14.29
Pave 30 mm DGA10(C170)	m^2	15.16	14.36	14.29
Pave 30 mm DGA10(A15E)	m^2	17.37	16.57	16.50
Mill 40 mm	m^2	7.64	7.29	7.25
Pave 40 mm DGA14(C320)	m^2	19.92	19.12	19.04
Pave 40 mm DGA14(A15E)	m^2	22.59	21.79	21.71
Pave 40 mm DGA14(A35P)	m^2	22.59	21.79	21.71
Mill 60 mm	m^2	11.46	10.94	10.88
10 mm SAMI seal	m^2	7.24	6.44	6.36
Mill 60 mm, and place SAMI + DGA10 +OGA	m^2	48.41	46.56	46.38
Mill 60 mm, and place SAMI + DGA10(PMB) +OGA	m^2	51.08	49.23	49.05
Mill 40 mm DGA, pave 40 mm DGA14(C320)	m^2	27.08	25.96	25.84
Mill 40 mm DGA, pave 40 mm DGA14(PMB)	m^2	29.75	28.63	28.51
Mill 30 mm DGA, place GRS, pave 30 mm DGA10(C170)	m^2	31.95	30.10	29.91
Mill 30 mm DGA, place GRS, pave 30 mm DGA10(PMB)	m^2	34.62	32.77	32.58
Mill 40 mm DGA, place GRS, pave 40 mm DGA14(C320)	m^2	34.78	32.84	32.64
Mill 40 mm DGA, place GRS, pave 40 mm DGA14(PMB)	m^2	37.45	35.51	35.31
Mill 60 mm, place GRS, pave 30 mm DGA10 + 30 mm OGA	m^2	53.09	51.18	50.99
Mill 60 mm, place GRS, pave 30 mm DGA10(PMB) + 30 mm OGA	m^2	55.30	53.39	53.20
Mill 70 mm, place SAMI, pave 40 mm DGA14 + 30 mm OGA	m^2	51.24	49.30	49.11
Mill 70 mm, place SAMI, pave 40 mm DGA14(PMB) + 30 mm OGA	m^2	53.91	51.97	51.78
Heavy patching over 1% of area	m^2	1.39	1.39	1.39
Routine maintenance	m^2	0.29	0.29	0.29

6.2 Discount Rate

The discount rate needs to be selected to express future expenditure in terms of present values and costs. Main Roads WA advised that the WOLCC should be undertaken using a discount rate of 7% in line with the official WA Treasury discount rate. The WOLCC Calculator supplied to Main Roads WA allows the sensitivity of the WOLCC to the discount rate to be evaluated.

6.3 Discounted Maintenance Costs

The discounted maintenance costs are the total maintenance costs over the 40 year analysis period calculated from the type and timing of the maintenance treatments (refer Section 5), the unit rates for maintenance and the discount rate.

Table 6.2 lists the discounted (7%) maintenance costs for Perth region. Appendix E lists these costs for all four regions.

Table 6.2: Discounted maintenance costs for Perth region

Pavement type	Surface description	DGA with C170 or C320 bitumen			DGA with polymer modified C170 or C320 bitumen		
		Small-scale $/m²	Medium-scale $/m²	Large-scale $/m²	Small-scale $/m²	Medium-scale $/m²	Large-scale $/m²
1a	30 mm DGA	15	14	14	16	15	15
	40 mm DGA (mid block)	18	17	17	19	18	18
	40 mm DGA (intersections)	32	30	30	34	33	33
	30 mm OGA on 30 mm DGA	44	43	43	46	44	44
1a5	30 mm DGA	16	15	15	17	17	17
	40 mm DGA (mid block)	19	18	18	20	19	19
	40 mm DGA (intersections)	34	32	32	36	35	35
	30 mm OGA on 30 mm DGA	45	43	43	47	45	45
1b, 1c and 1d	30 mm DGA	47	44	44	50	48	48
	40 mm DGA (mid block)	50	48	48	54	51	51
	30 mm OGA on 30 mm DGA	74	72	71	77	75	74
2, 3 and 4	40 mm DGA (mid block)	18	17	17	19	18	18
	40 mm DGA (intersections)	31	30	30	34	32	32
	30 mm OGA on 30 mm DGA	46	45	44	48	47	47
5	Plain concrete pavement (PCP)	18	18	18	18	18	18
6	Continuously reinforced concrete pavement (CRCP)	7	7	7	7	7	7
6a	Continuously reinforced concrete pavement (CRCP) with open graded asphalt surfacing	32	31	30	32	31	30

For Perth freeways which require an open graded asphalt surface, maintenance costs are ranked as follows from lowest to highest:

- continuously reinforced concrete pavement with open graded asphalt surface (Type 6a)
- full-depth asphalt (Type 2), flexible composite (Type 3) and deep strength asphalt (Type 4)
- thin asphalt surfaced HCTCRB pavements (Types 1b, 1c, 1d).

For Perth arterials with a dense graded asphalt or concrete surface, maintenance costs are ranked as follows from lowest to highest:

- continuously reinforced concrete pavement (Type 6)
- thin asphalt on crushed rock base (P1a, P1a5), full-depth asphalt (Type 2), flexible composite (Type 3), deep strength asphalt (Type 4) and plain concrete pavement (Type 5)
- thin asphalt surfaced HCTCRB pavements (Types 1b, 1c, 1d).

Note that the maintenance costs for pavements with polymer modified asphalt DGA14 are marginally higher than for pavements with conventional binders. This is due to:

- the additional costs of the polymer modified binder
- the adoption of the same maintenance treatments regardless of whether the polymer is used or not (refer Section 5.1).

7 RESIDUAL VALUE

The residual value of each pavement at the end of the 40 year analysis period is difficult to assess and is dependent on several factors, including the:

- continued use of an existing alignment and geometric standards
- feasibility of upgrading or strengthening a pavement with an overlay
- possibility of recycling existing paving materials, either in plant or in situ
- need to remove the pavement before reconstruction.

In this analysis, the residual values were calculated as the sum of:

- the residual value of the surfacing, calculated by multiplying the last resurfacing cost by the proportion of service life remaining
- the residual value of the underlying pavement structure, calculated by multiplying the cost of the last reconstruction less surfacing cost by the proportion of structural life remaining. However, in the adopted maintenance scenarios (Section 5), none of the pavement configurations require reconstruction in the 40 year analysis period. In calculating the residual value it was assumed that 50% of the structural life remained at 40 years.

For a discount rate of 7%, the residual values were less than 5% of the WOLCC.

8 ROAD AGENCY WHOLE-OF-LIFE-CYCLE COSTS

8.1 Analysis Period and Discount Rates

The analysis period is the length of time for which comparisons of the whole-of-life-cycle costs (WOLCC) are to be made. It should be the same for all pavement types and should not be less than the longest design period of the alternative strategies. In consultation with Main Roads WA, a 40 year analysis period was selected for the WOLCC, this being the same as the period used in the structural design.

The discount rate needs to be selected to express future expenditure in terms of present values and costs. In this report, the WOLCC analysis has been undertaken at a discount rate of 7%. This is in line with the official Western Australian Treasury discount rate. The WOLCC Calculator developed in this project enables sensitivity analysis at other discount rates.

8.2 WOLCC Results

In all, WOLCC were calculated for about 25,000 cases.

Described below are selected examples of the WOLCC for Perth region. Example costs for all four regions are listed in Appendix D.

8.2.1 Perth Freeways

Figure 8.1 and Figure 8.2 are examples of the calculated WOLCC for freeways in Perth using unit rates for large-scale works. The surfacing comprises an open graded asphalt wearing course with:

- 30 mm thick size 10 dense graded asphalt with C170 bitumen on granular pavements (P1a, P1a5, P1b, P1c, P1d); or
- 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen on full-depth asphalt, flexible composite and deep strength asphalt pavements (P2, P3 and P4); or
- continuously reinforced concrete base (P6a).

As expected for the more lightly-loaded freeways (< 8 x 10^7 ESA), thin asphalt surfaced HCTCRB pavements are clearly the lowest cost. For the common case of a subgrade design CBR of 12%, Figure 4.2 indicates that HCTCRB on crushed limestone subbase (P1b) and full-depth HCTCRB (P1d) pavements have similar WOLCC and maximum design traffic loadings.

For freeways which have a 40 year design traffic loading exceeding the maximum allowable loading (about 8 x10^7 ESA) of thin asphalt surfaced HCTCRB pavements, the full-depth asphalt (P2) or deep strength asphalt (P4) pavements are the lowest cost options.

The CRCP concrete pavement with open graded asphalt surface (P6a) is clearly the highest cost.

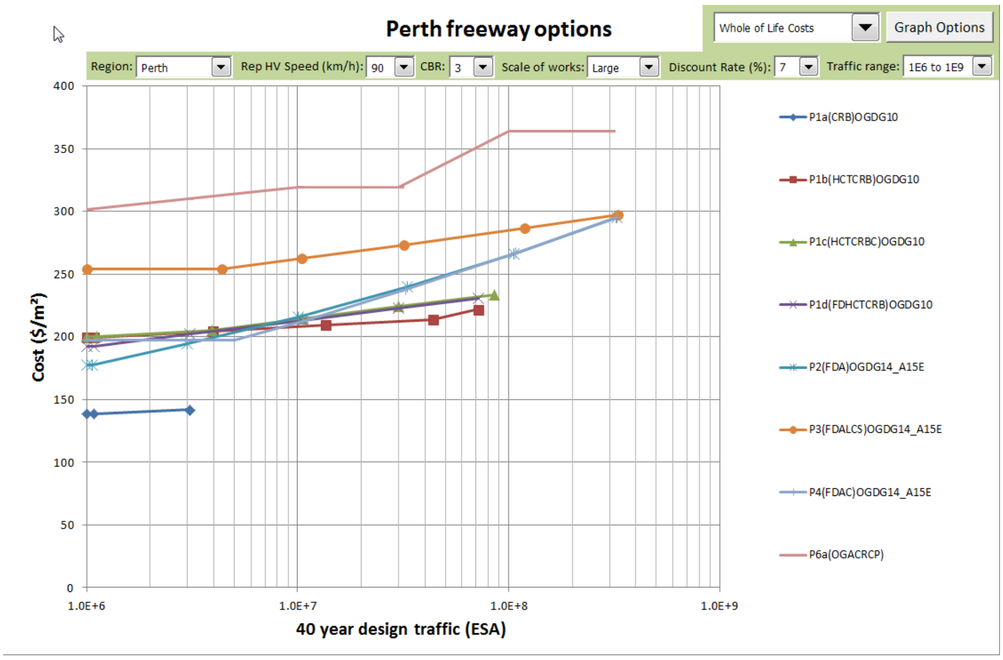

Figure 8.1: WOLCC for Perth freeways with open graded asphalt surfacing, subgrade design CBR = 3% and design speed 90 km/h

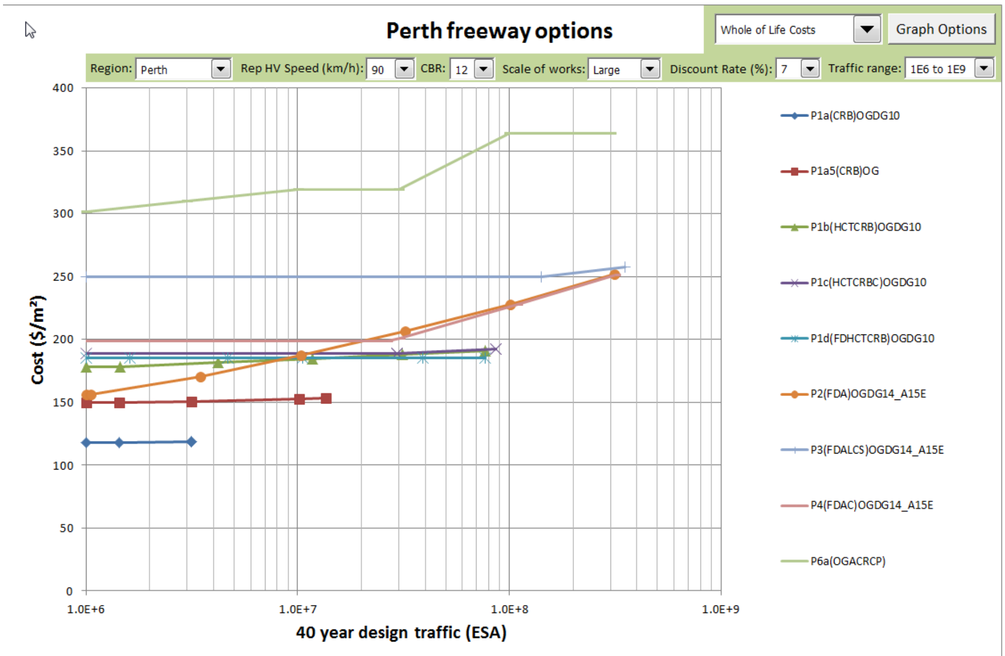

Figure 8.2: WOLCC for Perth freeways with open graded asphalt surfacings, subgrade design CBR = 12% and design speed 90 km/h

8.2.2 Perth Arterial Roads

Figure 8.3 and Figure 8.4 are WOLCC examples for Perth arterial roads based on unit rates for medium-scale works. Except for the concrete pavement options, the wearing course was either:

- 30 mm thick size 10 dense graded asphalt with C170 bitumen (P1a, P1a5, P1b. P1c, P1d) or

- 40 mm thick size 14 dense graded asphalt with A15E polymer modified C320 bitumen (P2, P3 and P4).

As part of the project, Main Roads WA requested evaluation of Pavement Type 1a5, thin asphalt surfaced crushed rock base pavements designed with a 5 year asphalt fatigue life rather than the current practice of specifying a 15 year fatigue life. This design criteria is only for Perth pavements on sand subgrades (CBR = 12%).

Figure 8.3 and Figure 8.4 indicate that asphalt on crushed rock base (Types P1a and P1a5) have the lowest WOLCC for Perth arterial roads. For commonly used subgrade design CBR of 12% (sand), the maximum allowable traffic loading over 40 years of thin asphalt surface granular pavements with 5 year fatigue life (P1a5) is about 3 x 10^7 ESA. For more heavily trafficked arterials, thin asphalt on full-depth HCTCRB pavements (P1d) have the lowest WOLCC.

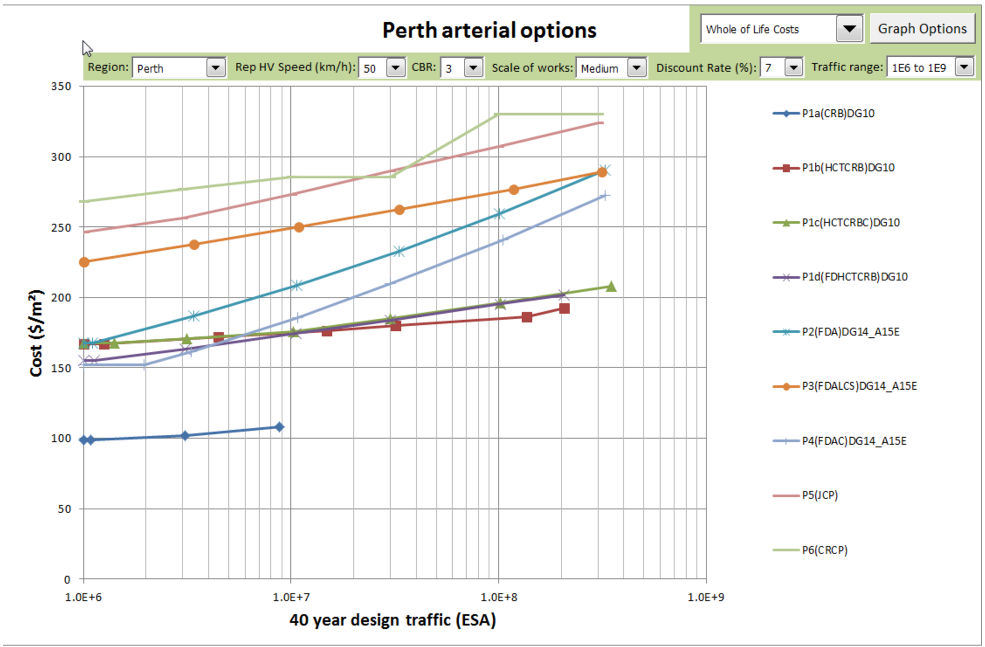

Figure 8.3: **WOLCC for Perth region urban arterials with dense graded asphalt surfacing, subgrade design CBR = 3% and design speed 50 km/h**

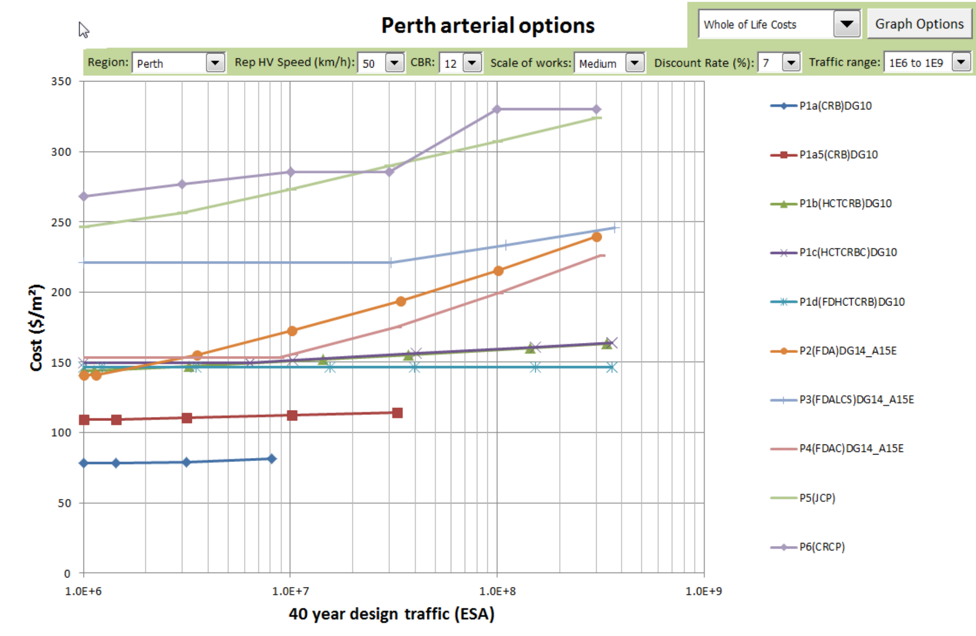

Figure 8.4: WOLCC Perth region urban arterials with dense graded asphalt surfacing, subgrade design CBR = 12% and design speed 50 km/h

8.2.3 Perth Signalised Intersections

Figure 8.5 and Figure 8.6 are examples of the calculated WOLCC for Perth signalised intersections based on unit rates for small-scale works. Except for the concrete pavement options, the wearing course is 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen.

Figure 8.5 and Figure 8.6 indicate that thin asphalt surfaced crushed rock base pavements (P1a and P1a5) have the lowest construction costs. For commonly used subgrade design CBR of 12% (sand), the maximum allowable traffic loading over 40 years of thin asphalt surface granular pavements with 5 year fatigue life (P1a5) is about 8 x 10^6 ESA. Note that although the Main Roads WA procedures for pavement design (ERN 9) requires the use of polymer modified binder A15E at intersections for rut-resistance, no allowance is made for the calculated increase in fatigue life due its lower modulus. As most signalised intersections have a 40 year design traffic loading greater than 10^7 ESA, generally thick asphalt on cement treated crushed rock subbase pavements (P4) have the lowest WOLCC.

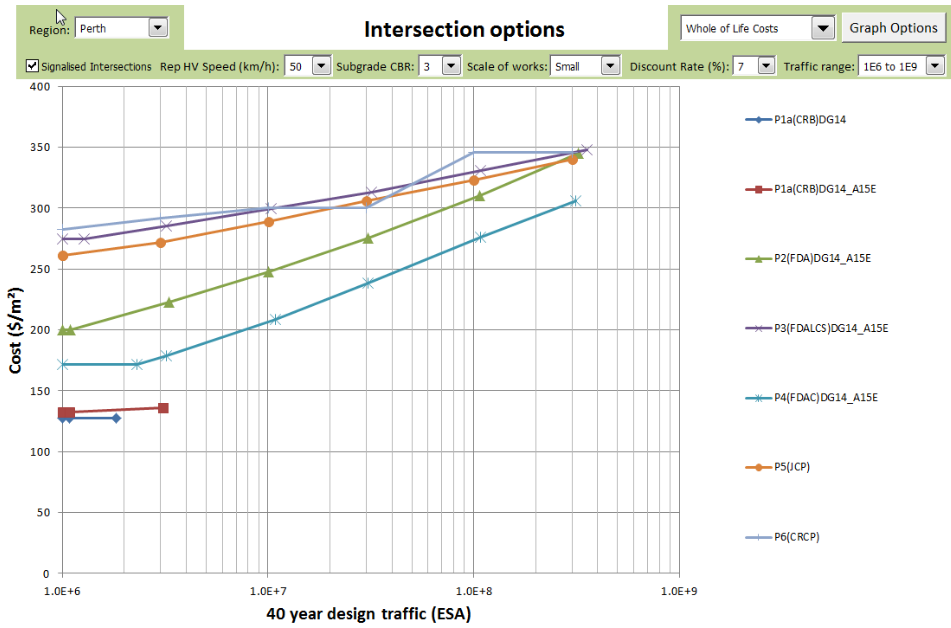

Figure 8.5: WOLCC for Perth region signalised intersections, subgrade design CBR = 3% and design speed 10 km/h

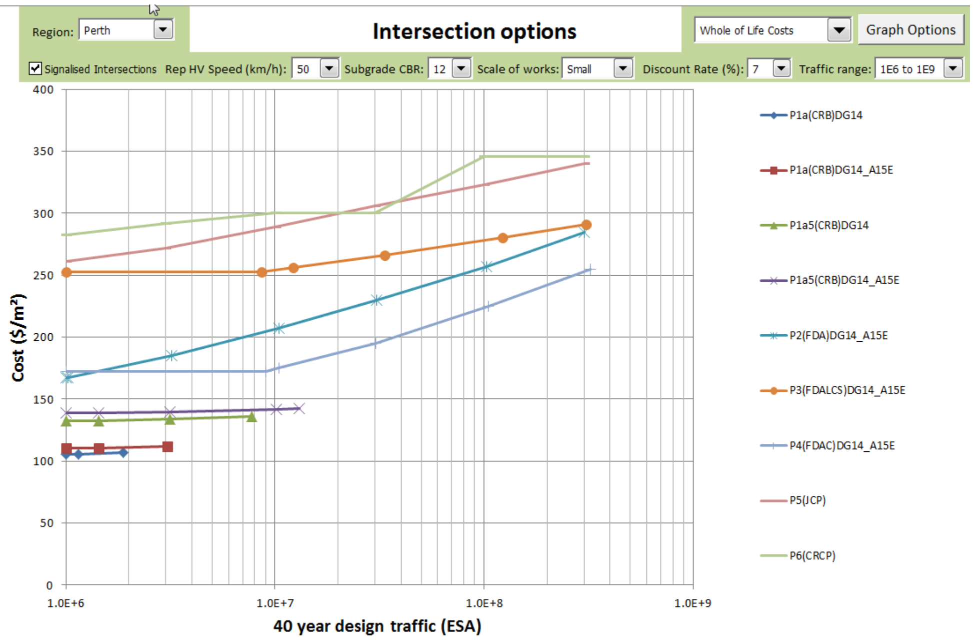

Figure 8.6: WOLCC for Perth region signalised intersections, subgrade design CBR = 12%

8.3 Bunbury, Port Hedland and Broome Regions Costs

Examples of initial construction costs for Bunbury, Port Hedland and Broome regions are listed in Appendix F.

The most common regional applications of asphalt surfaced and concrete surfaced pavements designs are signalised intersections for which a sprayed seal surface has inadequate shear resistance. Figure 8.7, Figure 8.8 and Figure 8.9 illustrate the WOLCC for a subgrade design CBR=12%.

For Bunbury and Port Hedland regions, except for very lightly-trafficked roads (< 10^7 ESA), thick asphalt on cement treated crushed rock subbase pavements (P4) are the lowest cost.

For Broome the thin asphalt surfaced granular pavements have the lowest WOLCC up to about 2 x 10^7 ESA beyond which they have inadequate fatigue life. For higher traffic loadings once again deep strength asphalt pavements (P4) have the lowest WOLCC.

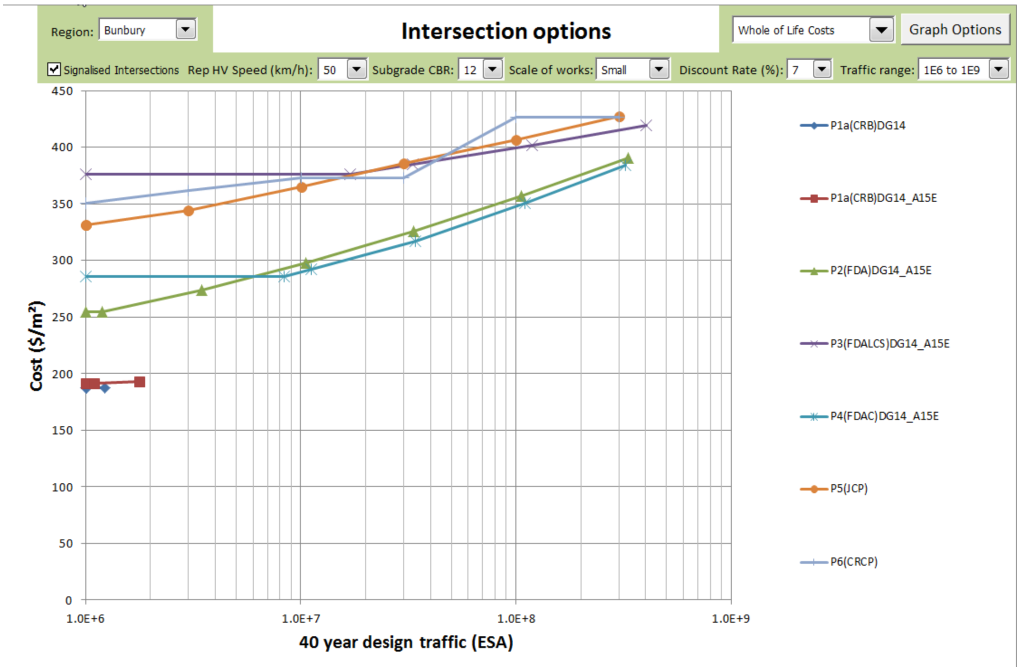

Figure 8.7: WOLCC for Bunbury region signalised intersections with dense graded asphalt surfacing, subgrade design CBR = 12%

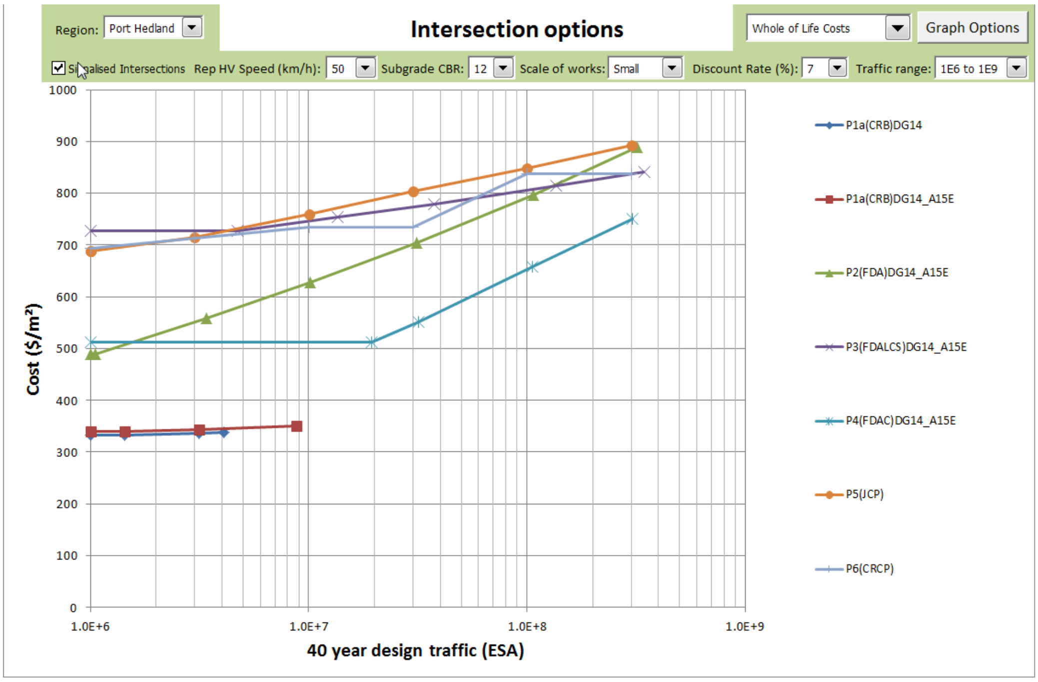

Figure 8.8: WOLCC for Port Hedland region signalised intersections with dense graded asphalt surfacing, subgrade design CBR = 12%

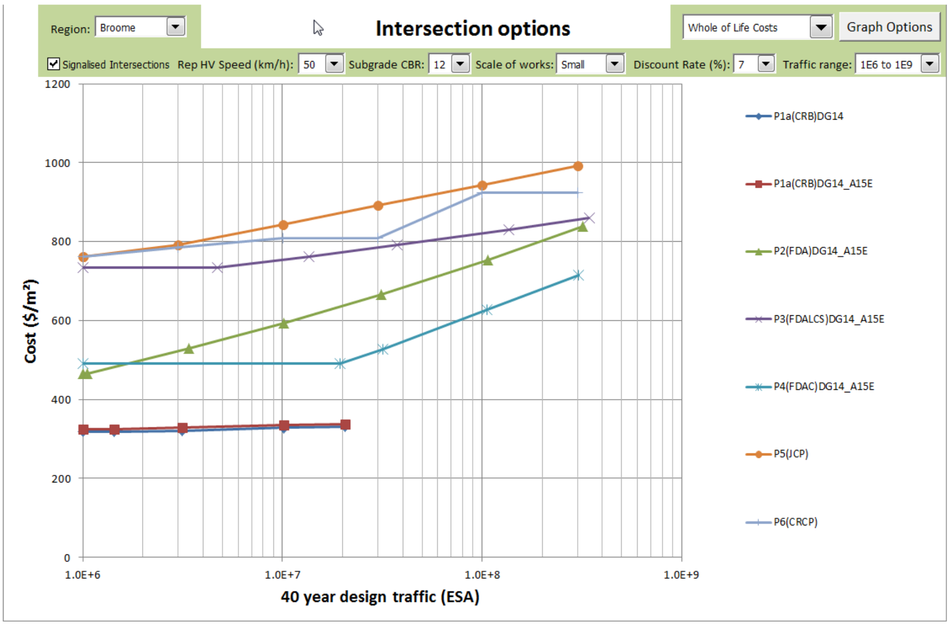

Figure 8.9: WOLCC for Broome region signalised intersections with dense graded asphalt surfacing, subgrade design CBR = 12%

8.4 Summary

For a discount rate of 7%, generally the pavements were ranked lowest to highest in terms of WOLCC:

- thin asphalt surfaced pavements with crushed rock base (Types 1a, 1a5)
- thin asphalt surfaced pavements with HCTCRB (Types 1b, 1c and 1d)

- full-depth asphalt (Type 2) and deep strength asphalt (Type 4)
- flexible composite (Type 3)
- concrete pavements (Types 5, 6 and 6a).

This is the same order as the initial construction costs (Section 4).

9 SUMMARY AND CONCLUSIONS

Road agency whole-of-life-cycle costs (WOLCC) of a wide variety of asphalt surfaced pavements, plain concrete pavements and continuously reinforced concrete pavements were calculated for various surfacing types, Western Australian regions/climates, subgrade strength, traffic speed and loadings. WOLCC were calculated for Bunbury, Perth, Port Hedland and Broome regions. Main Roads WA supported the project including designing a very large number of pavement configurations and providing the unit rates for the costing.

The project objective was to provide recommendations on the optimal pavement configuration for pavements with asphalt wearing courses based on the above factors (i.e. varying traffic loadings, climatic conditions, and costs). As there were about 25 000 pavement configurations analysed, a WOLCC Calculator was developed to enable the WOLCC to be calculated for a wide range of scenarios. Recommendations for optimal configurations are best undertaken on a project-by-project basis using the WOLCC Calculator.

Recycled crushed concrete (RCC) has potential use as high modulus subbase. Design and costs of pavement configurations with RCC were not included in the analysis pending a resolution of health and safety issues related to its use. In addition, there is limited availability of RCC for large scale works. It is recommended that Main Roads WA monitor developments and reconsider inclusion of RCC in future research on optimal pavement configurations.

In terms of flexible pavement configurations, the pavement types analysed included pavements for which Main Roads WA have yet to have experience. Outside the Perth metropolitan area, thin asphalt surfaced granular pavements are commonly used. There has been very limited use of all other pavement configurations (e.g. full-depth asphalt, thin asphalt surfaced hydrated cement treated crushed rock base (HCTCRB). In the Perth region, full-depth HCTCRB was included in the analysis, but this pavement type is yet to be constructed in Western Australia. This lack of field experience needs to be appreciated when drawing conclusions from the WOLCC reported herein.

In addition, it is understood that Western Australian contractors and consultants currently consider thin asphalt surfaced HCTCRB pavements have a higher risk of premature distress than other pavement types, based on recent poor performance issues on HCTCRB pavements. Since this initial experience, Main Roads WA have tightened up design criteria and specifications to address this risk, as reflected in the designs and the maintenance treatments utilised in the WOLCC analysis. It is anticipated that Main Roads WA will need to implement these changes on construct only jobs and monitor the in service performance of this pavement type for contractors and consultants to have confidence in this pavement type. This needs to be appreciated in utilising the WOLCC findings of this research project.

Guidance was also required about when concrete pavements are the preferred pavement option (i.e. traffic loading or climatic conditions). Across a wide range of pavement configurations and regions, the concrete pavement types had considerably higher costs than thin asphalt surfaced granular, full-depth asphalt and deep strength asphalt pavements. Although the estimated maintenance costs of the concrete pavements were lower than other pavement types, their high initial construction costs result in high WOLCC. The high construction costs compared to eastern states may reflect the fact that the concrete pavement industry in Western Australia is in its infancy. The plain concrete pavements and continuously reinforced pavements were similar in initial costs, which is not consistent with experience in New South Wales. It is recommended that Main Roads WA review the unit rates for concrete pavements when actual construction cost data becomes available from concrete pavement projects in progress.

In addition, the base thicknesses designed for the concrete pavements were very high compared to those used in New South Wales. The principal reason for the high thicknesses is the high damage due to the twin steer axles number and distribution of axle loads. It is recommended that Main Roads WA reconsider the axle load distribution used in the analysis.

If Main Roads WA confirms the use of both the current unit rates and the axle load distribution, the use of concrete pavements would appear to be limited to special applications, for instance in situations where either due to high temperature, low traffic loadings and/or turning or braking traffic, an asphalt surface does not provide an adequate service life.

Appendix F includes examples of WOLCC for specific scenarios to illustrate the WOLCC Calculator application for all four regions. The findings from these examples for the Perth region were:

Freeways

For higher traffic speed pavements that require an open graded asphalt surfacing for noise, spray and/or skid resistance (e.g. freeways), the pavement type with the lowest WOLCC varies with the traffic loading. For freeways with lower volumes of heavy vehicles ($\leq 8 \times 10^7$ ESA) the thin asphalt surfaced HCTCRB pavement options clearly have the lowest WOLCC. For sand subgrades common in Perth, the full-depth HCTCRB was lowest in cost. The use of A15E polymer modified binder in the size 10 mm dense graded asphalt under the open graded asphalt surfacing, not only improves rut-resistance but significantly increases the maximum design traffic loading applicable for this pavement type to about 10^8 ESA. However, Main Roads WA design procedures (ERN9) currently does not allow for this enhanced structural capacity at present.

For 40 year traffic loadings above about 8×10^7 ESA, the thin asphalt surfaced HCTCRB pavement options cannot be designed to achieve a 15 year asphalt fatigue life. For such heavily trafficked urban freeways, full-depth and deep strength asphalt pavements have the lowest WOLCC.

The two concrete pavement types (P5 and P6) and the thick asphalt on lean concrete subbase (P3) are clearly higher in cost.

Arterial roads

For pavements where a 30 mm thick surfacing of size 10 dense graded asphalt (DGA10) is functionally adequate, thin asphalt surfaced crushed rock base pavements had both the lowest initial construction costs and WOLCC over the wide range of conditions investigated.

However, using the current 15 year asphalt fatigue life design criteria, this pavement has limited application as the maximum 40 year design traffic loading is about 8×10^6 ESA. In the Perth region, Main Roads WA' experience with this pavement type on sand subgrades cover with crushed limestone subbase is that the thin asphalt surfacing is capable of operating at considerably higher design traffic loadings than predicted by the design model.

To provide for this in the WOLCC analysis, Main Roads WA requested the analysis also include thin asphalt surfaced crushed rock base pavements with a 5 year design life for fatigue of thin surfacing. This pavement type has the lowest WOLCC for traffic loadings up to about 3×10^7 ESA. For higher traffic loadings, full-depth HCTCRB pavements have the lowest WOLCC.

Signalised intersections

Main Roads WA practice is to surface signalised intersections using a 40 mm thickness of DGA14 intersection mix, with the C320 bitumen modified with A15E polymer. Generally thick asphalt on cement treated crushed rock subbase (P4) the lowest cost for all regions.

The project involved estimating the WOLCC road agency costs. Based on the findings of this report, Main Roads WA will decide whether to proceed with the estimation of the road user costs and hence the total WOLCC.

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APPENDIX A TRAFFIC LOAD DISTRIBUTION

Table A 1: Traffic load distribution (%)

Axle Group Load (kN)	Axle Group Type					
	SAST	SADT	TAST	TADT	TRDT	QADT
10	5.8921	16.4096	0.5342	0.7423	0.0032	
20	25.6345	32.0016	0.1214	1.8700	0.0601	
30	10.5723	11.3824	0.2671	1.3799	0.2119	
40	7.1698	9.5948	0.8742	1.2514	0.4238	
50	9.7216	8.2274	0.5342	3.2950	1.1703	
60	20.4841	6.9558	0.5100	6.5116	5.8673	
70	17.1335	5.3176	2.3312	8.5243	10.1594	
80	3.1570	3.7105	5.0753	7.8986	7.2874	
90	0.2351	3.1917	13.0403	6.7732	4.4028	
100		1.9708	17.0471	5.4552	3.8209	8.0000
110		0.8797	28.9704	4.8747	3.3338	4.0000
120		0.2763	30.6945	4.9271	2.9605	8.0000
130		0.0648		6.7114	2.7454	16.0000
140		0.0113		6.1333	2.6474	16.0000
150		0.0056		6.7566	2.5304	
160				7.5322	2.3785	
170				7.8058	2.3216	
180				5.9334	2.6379	
190				3.4782	2.6189	
200				1.4370	3.2136	8.0000
210				0.4948	4.5673	
220				0.1451	5.9653	
230				0.0452	7.0059	
240				0.0190	6.8004	4.0000
250				0.0048	6.2563	4.0000
260					4.6938	8.0000
270					2.5209	
280					0.9837	
290					0.3226	
300					0.0664	4.0000
310					0.0127	8.0000
320					0.0095	4.0000
330						4.0000
340						
350						4.0000
360						
370						
380						
390						
400						
410						
420						
430						
440						
450						
460						
470						
480						
490						
500						
Total	100.00	100.00	100.00	100.00	100.00	100.00
Proportion of Each Axle Group (%)	33.80	20.73	2.41	24.57	18.48	0.01
N_{HVAG}	ESA/HVAG	ESA/HV	SAR5/ESA	SAR7/ESA	SAR12/ESA	
2.76	1.03	2.86	1.25	2.08	9.85	

APPENDIX B ASPHALT CHARACTERISATION

Table B 1: Asphalt characterisation for a weight mean annual pavement temperature (WMAPT) = 25 °C

Mix type	Volume of binder (%)	Design modulus (MPa)					
		10 km/h	50 km/h	70 km/h	80 km/h	90 km/h	100 km/h
Pavement Types 1a, 1a5, 1b, 1c and 1d							
Open graded asphalt Class 320 (OGA)	N/A	N/A	N/A	2000	N/A	2500	2500
DGA10 Class 170 binder	11.8	1800	3300	3700	N/A	4100	4200
DGA10 A15E binder	11.8	1400	2500	2800	N/A	3000	3200
DGA14 Class 320 binder	10.3	1900	3500	3900	4100	N/A	N/A
DGA14 A15E binder	10.3	1400	2600	2900	3100	N/A	N/A
Pavement Types 2, 3 and 4							
Open graded asphalt Class 320 (OGA)	N/A	N/A	N/A	800	N/A	800	800
DGA14 Class 320 binder	10.3	1700	3100	3600	3700	3900	4000
DGA14 Class 320 modified with A15E binder	10.3	1300	2400	2700	2800	2900	3000
DGA14 Class 320 modified with A35P binder	10.3	2200	3900	4400	4700	4900	5100
DGA20 Class 320 binder	10.0	2100	3700	4200	4400	4600	4800

Table B 2: Asphalt characterisation for a weight mean annual pavement temperature (WMAPT) = 29 °C

Mix type	Volume of binder (%)	Design modulus (MPa)					
		10 km/h	50 km/h	70 km/h	80 km/h	90 km/h	100 km/h
Pavement Types 1a, 1b, 1c and 1d							
Open graded asphalt Class 320 (OGA)	N/A	N/A	N/A	2000	N/A	2500	2500
DGA10 Class 170 binder	11.8	1300	2400	2700	2800	2900	3100
DGA10 A15E binder	11.8	1000	1800	2000	2100	2200	2300
DGA14 Class 320 binder	10.3	1400	2500	2800	3000	N/A	N/A
DGA14 A15E binder	10.3	1000	1900	2100	2200	N/A	N/A
Pavement Types 2, 3 and 4							
Open graded asphalt Class 320 (OGA)	N/A	N/A	N/A	800	N/A	800	800
DGA14 Class 320 binder	10.3	1300	2300	2600	2700	2800	2900
DGA14 mix Class 320 modified with A15E binder	10.3	1000	1700	1900	2000	2100	2200
DGA14 Class 320 modified with A35P binder	10.3	1600	2900	3200	3400	3500	3700
DGA20 mix Class 320 binder	10.0	1500	2700	3000	3200	3300	3500

Table B 3: Asphalt characterisation for a Weight Mean Annual Pavement Temperature (WMAPT) = 34 °C

Mix type	Volume of binder (%)	Design modulus (MPa)					
		10 km/h	50 km/h	70 km/h	80 km/h	90 km/h	100 km/h
Pavement Types 1a, 1b, 1c and 1d							
Open graded asphalt Class 320 (OGA)	N/A	N/A	N/A	2000	N/A	2500	2500
DGA10 Class 170 binder	11.8	1000	1600	1800	N/A	2000	2000
DGA10 A15E binder	11.8	1000	1200	1300	N/A		
DGA14 Class 320 binder	10.3	1000	1700	1900	2000	N/A	N/A
DGA14 A15E binder	10.3	1000	1300	1400	1500	N/A	N/A
Pavement Types 2, 3 and 4							
Open graded asphalt Class 320 (OGA)	N/A	N/A	N/A	800	N/A	800	800
DGA14 Class 320 binder	10.3	1000	1500	1700	1800	1900	2000
DGA14 Class 320 modified with A15E binder	10.3	1000	1100	1300	1400	1400	1500
DGA14 Class 320 modified with A35P binder	10.3	1100	1900	2200	2300	2400	2500
DGA20 mix Class 320 binder	10.0	1000	1800	2000	2100	2200	2300

Table B 4: Asphalt characterisation for a weight mean annual pavement temperature (WMAPT) = 40 °C

Mix type	Volume of binder (%)	Design modulus (MPa)					
		10 km/h	50 km/h	70 km/h	80 km/h	90 km/h	100 km/h
Pavement Types 1a, 1b, 1c and 1d							
Open graded asphalt Class 320 (OGA)	N/A	N/A	N/A	2000	N/A	2500	2500
DGA10 Class 170 binder	11.8	1000	1000	1100	1200	1200	1300
DGA10 A15E binder	11.8	1000	1000	1000	1000	1000	1000
DGA14 Class 320 binder	10.3	1000	1000	1200	1200	N/A	N/A
DGA14 A15E binder	10.3	1000	1000	1000	1000	N/A	N/A
Pavement Types 2, 3 and 4							
Open graded asphalt Class 320 (OGA)	N/A	N/A	N/A	800	N/A	800	800
DGA14 Class 320 binder	10.3	1000	1000	1100	1100	1200	1200
DGA14 Class 320 modified with A15E binder	10.3	1000	1000	1000	1000	1000	1000
DGA14 Class 320 modified with A35P binder	10.3	1000	1200	1300	1400	1500	1500
DGA20 Class 320 binder	10.0	1000	1100	1300	1300	1400	1400

APPENDIX C UNIT COST RATES

C.1 Initial construction rates

Table C 1: Unit rates for Bunbury region

Pavement layer / treatment	Unit	Unit rate ($)		
		Small-scale	Medium-scale	Large-scale
Flexible pavements				
Size 10 mm OGA, 30 mm thickness	m^2	19.55	16.80	16.53
Size 10 mm DGA, 30 mm thickness	m^2	19.55	16.80	16.53
Size 10 mm DGA, Class 170 modified with A15E binder, 30 mm thickness	m^2	21.94	19.19	18.92
Size 14 mm DGA IM, 40 mm thickness	m^2	25.05	22.30	22.03
Size 14 mm DGA IM Class 320 modified with A15E or A35P binder, 40 mm thickness	m^2	27.94	25.19	24.92
Size 14 mm DGA IM, 50 mm thickness	m^2	30.55	27.80	27.53
Size 14 mm DGA IM Class 320 modified with A15E or A35P binder, 50 mm thickness	m^2	34.16	31.41	31.14
Double/double 14/7 heavy grade fabric geotextile reinforced seal (GRS)	m^2	20.81	10.82	10.42
Single coat, 10 mm seal	m^2	7.24	4.49	4.21
Prime coat	m^2	1.25	1.25	1.25
2-coat emulsion seal	m^2	11.42	8.67	8.40
Tack coat	m^2	1.25	1.25	1.25
Size 14 mm, DGA, intermediate	m^3	611	556	551
Size 20 mm, DGA, intermediate	m^3	611	556	551
Crushed rock base (CRB)	m^3	149	122	119
Hydrated cement-treated crushed rock base (HCTCRB)	m^3	204	177	174
Crushed limestone subbase	m^3	144	116	114
Gravel subbase	m^3	87.61	60.11	57.36
2% cement-treated crushed rock subbase	m^3	279	250	248
Lean concrete subbase (screened wet), including bitumen emulsion seal for curing / bonding	m^3	946	920	918
Concrete pavements				
Jointed plain concrete base, including supply, placement, curing, texturing, joint seals	m^3	829	803	800
Continuously reinforced concrete base, including supply, placement concrete & steel, curing & texturing	m^3	1,076	1,050	1,047
Size 10 mm OGA, 30 mm thickness	m^2	19.55	16.80	16.53
Prime coat	m^2	1.25	1.25	1.25
10 mm PMB seal	m^2	9.99	7.24	6.96
Lean concrete subbase, 5 MPa, subbase slip-formed, curing & debonding	m^3	851	736	642

Table C 2: Unit rates for Perth region

Pavement layer / treatment	Unit	Unit rate ($)		
		Small-scale	Medium-scale	Large-scale
Flexible pavements				
Size 10 mm OGA, 30 mm thickness	m^2	15.16	14.36	14.28
Size 10 mm DGA, 30 mm thickness	m^2	15.16	14.36	14.28
Size 10 mm DGA, Class 170 modified with A15E binder, 30 mm thickness	m^2	17.37	19.12	16.50
Size 14 mm DGA IM, 40 mm thickness	m^2	19.92	19.12	19.04
Size 14 mm DGA IM, Class 320 modified with A15E or A35P binder, 40 mm thickness	m^2	22.59	21.79	21.71
Size 14 mm DGA IM, 50 mm thickness	m^2	24.67	23.88	23.80
Size 14 mm DGA IM Class 320 modified with A15E or A35P binder, 50 mm thickness	m^2	28.01	27.22	27.14
Double/double 14 mm / 7 mm heavy grade fabric geotextile reinforced seal (GRS)	m^2	15.08	9.62	9.52
Single coat, 10 mm seal	m^2	4.69	3.90	3.82
Prime coat	m^2	1.13	1.13	1.13
2-coat emulsion seal	m^2	8.50	7.71	7.63
Tack coat	m^2	1.13	1.13	1.13
Size 14 mm, DGA, intermediate	m^3	493	478	476
Size 20 mm, DGA, intermediate	m^3	493	478	476
Crushed rock base (CRB)	m^3	109	104	104
Hydrated cement-treated crushed rock base (HCTCRB)	m^3	163	159	158
Crushed limestone subbase	m^3	103	99.06	98.62
Gravel subbase	m^3	49.54	45.13	44.69
2% cement-treated crushed rock subbase	m^3	171	167	166
Lean concrete subbase (screened wet), including bitumen emulsion seal for curing / bonding	m^3	767	760	759
Concrete pavements				
Jointed plain concrete base, including supply, placement, curing, texturing, joint seals	m^3	676	669	668
Continuously reinforced concrete base, including supply, placement concrete & steel, curing & texturing	m^3	892	884	884
Size 10 mm OGA, 30 mm thickness	m^2	19.55	16.80	16.53
Prime coat	m^2	1.25	1.25	1.25
10 mm PMB seal	m^2	7.24	6.44	6.36
Lean concrete subbase, 5 MPa, subbase slip-formed, curing & debonding	m^3	690	608	532

Table C 3: Unit rates for Port Hedland region

Pavement layer / treatment	Unit	Unit rate ($)		
		Small-scale	Medium-scale	Large-scale
Flexible pavements				
Size 10 mm OGA, 30 mm thickness	m^2	57.10	31.41	28.84
Size 10 mm DGA, 30 mm thickness	m^2	57.10	31.41	28.84
Size 10 mm DGA with A15E binder, 30 mm thickness	m^2	60.04	34.35	31.78
Size 14 mm DGA IM, 40 mm thickness	m^2	66.62	40.93	38.36
Size 14 mm DGA IM, Class 320 modified with A15E or A35P binder, 40 mm thickness	m^2	70.18	44.49	41.92
Size 14 mm DGA IM, 50 mm thickness	m^2	76.14	50.44	47.87
Size 14 mm DGA IM Class 320 modified with A15E or A35P binder, 50 mm thickness	m^2	80.59	54.89	52.32
Double/double 14 mm / 7 mm heavy grade fabric geotextile reinforced seal (GRS)	m^2	55.75	17.36	13.52
Single coat, 10 mm seal	m^2	34.85	9.15	6.58
Prime coat	m^2	1.82	1.82	1.82
2-coat emulsion seal	m^2	41.14	15.45	12.88
Tack coat	m^2	1.82	1.82	1.82
Size 14 mm, DGA, intermediate	m^3	1,523	1,009	957
Size 20 mm, DGA, intermediate	m^3	1,523	1,009	957
Crushed rock base (CRB)	m^3	356	243	232
Hydrated cement-treated crushed rock base (HCTCRB)	m^3	411	298	287
Crushed limestone subbase	m^3	-	-	-
Gravel subbase	m^3	221	109	97.57
2% cement-treated crushed rock subbase	m^3	457	345	334
Lean concrete subbase (screened wet), including bitumen emulsion seal for curing / bonding	m^3	1,928	1,661	1,635
Concrete pavements				
Jointed plain concrete base, including supply, placement, curing, texturing, joint seals	m^3	1,764	1,498	1,471
Continuously reinforced concrete base, including supply, placement concrete & steel, curing & texturing	m^3	2,049	1,782	1,755
Size 10 mm OGA, 30 mm thickness	m^2	19.55	16.80	16.53
Prime coat	m^2	1.25	1.25	1.25
10 mm PMB seal	m^2	37.32	11.62	9.05
Lean concrete subbase, 5 MPa, subbase slip-formed, curing & debonding	m^3	1727	1322	1138

Table C 4: Unit rates adopted for Broome region

Pavement layer / treatment	Unit	Unit rate ($)		
		Small-scale	Medium-scale	Large-scale
Flexible pavements				
Size 10 mm OGA, 30 mm thickness	m^2	54.25	28.55	25.98
Size 10 mm DGA, 30 mm thickness	m^2	54.25	28.55	25.98
Size 10 mm DGA with A15E binder, 30 mm thickness	m^2	57.38	31.68	29.11
Size 14 mm DGA IM, 40 mm thickness	m^2	62.82	37.12	34.55
Size 14 mm DGA IM, Class 320 modified with A15E or A35P binder, 40 mm thickness	m^2	66.60	40.90	38.33
Size 14 mm DGA IM, 50 mm thickness	m^2	71.38	45.68	43.11
Size 14 mm DGA IM Class 320 modified with A15E or A35P binder, 50 mm thickness	m^2	76.10	50.40	47.83
Double/double 14 mm / 7 mm heavy grade fabric geotextile reinforced seal (GRS)	m^2	55.08	16.69	12.85
Single coat, 10 mm seal	m^2	34.49	8.79	6.23
Prime coat	m^2	1.58	1.58	1.58
2-coat emulsion seal	m^2	40.43	14.73	12.16
Tack coat	m^2	1.58	1.58	1.58
Size 14 mm, DGA, intermediate	m^3	1,428	914	862
Size 20 mm, DGA, intermediate	m^3	1,428	914	862
Crushed rock base (CRB)	m^3	328	216	204
Hydrated cement-treated crushed rock base (HCTCRB)	m^3	383	271	259
Crushed limestone subbase	m^3	-	-	-
Gravel subbase	m^3	214	102	90.56
2% cement-treated crushed rock subbase	m^3	462	350	339
Lean concrete subbase (screened wet), including bitumen emulsion seal for curing / bonding	m^3	2,142	1,876	1,849
Concrete pavements				
Jointed plain concrete base, including supply, placement, curing, texturing, joint seals	m^3	1,993	1,726	1,700
Continuously reinforced concrete base, including supply, placement concrete & steel, curing & texturing	m^3	2,273	2,006	1,980
Size 10 mm OGA, 30 mm thickness	m^2	19.55	16.80	16.53
Prime coat	m^2	1.25	1.25	1.25
10 mm PMB seal	m^2	36.87	11.17	8.60
Lean concrete subbase, 5 MPa, subbase slip-formed, curing & debonding	m^3	1928	1501	1295

C.2 Maintenance Unit Rates

Table C 5: Maintenance costs adopted for Bunbury region

Pavement layer / treatment	Unit	Unit rate ($)		
		Small-scale	Medium-scale	Large-scale
Flexible pavements				
Mill 30 mm	m^2	8.86	7.76	7.65
Pave 30 mm OGA	m^2	19.55	16.80	16.53
Pave 30 mm DGA10(C170)	m^2	19.55	16.80	16.53
Pave 30 mm DGA10(A15E)	m^2	21.94	19.19	18.92
Mill 40 mm	m^2	11.81	10.35	10.20
Pave 40 mm DGA14(C320)	m^2	25.05	22.30	22.03
Pave 40 mm DGA14(A15E)	m^2	27.94	25.19	24.92
Pave 40 mm DGA14(A35P)	m^2	27.94	25.19	24.92
Mill 60	m^2	17.72	15.52	15.30
Double/double 14 mm / 7 mm heavy grade fabric geotextile reinforced seal (GRS)	m^2	20.81	10.82	10.42
10 mm SAMI seal	m^2	9.99	7.24	6.96
Mill 60 mm, and place SAMI + DGA10 +OGA	m^2	63.18	56.58	55.92
Mill 60 mm, and place SAMI + DGA10(PMB) +OGA	m^2	66.07	59.47	58.81
Mill 40 mm DGA, pave 40 mm DGA14(C320)	m^2	36.13	32.00	31.59
Mill 40 mm DGA, pave 40 mm DGA14(PMB)	m^2	39.02	34.89	34.48
Mill 30 mm DGA, place GRS, pave 30 mm DGA10(C170)	m^2	42.30	35.70	35.04
Mill 30 mm DGA, place GRS, pave 30 mm DGA10(PMB)	m^2	45.19	38.59	37.93
Mill 40 mm DGA, place GRS, pave 40 mm DGA14(C320)	m^2	46.82	39.86	39.16
Mill 40 mm DGA, place GRS, pave 40 mm DGA14(PMB)	m^2	49.71	42.75	42.05
Mill 60 mm, place GRS, pave 30 mm DGA10 + 30 mm OGA	m^2	68.65	61.77	61.08
Mill 60 mm, place GRS, pave 30 mm DGA10(PMB) + 30 mm OGA	m^2	71.04	64.16	63.47
Mill 70 mm, place SAMI, pave 40 mm DGA14 + 30 mm OGA	m^2	67.70	60.74	60.04
Mill 70 mm, place SAMI, pave 40 mm DGA14(PMB) + 30 mm OGA	m^2	70.59	63.63	62.93
Heavy patching over 1% of area	m^2	66.43	59.83	59.17
Routine maintenance	m^2	0.29	0.29	0.29
Plain Concrete Pavements				
Retexturing concrete surface 30% area	m^2	7.17	6.84	6.81
Remove and replace silicon seals of transverse and longitudinal joints	m^2	15.33	15.33	15.33
Remove and replace concrete base slabs 0.5% area	m^2	1.56	1.54	1.54
Remove and replace concrete base and subbase	m^2	1.87	1.85	1.85
Cross-stitch plain concrete pavements 20 m / lane-km	m^2	1.56	1.28	1.23
Cross-stitch plain concrete pavements 40 m / lane-km	m^2	3.11	2.55	2.45
Rout & seal 10% of cross-stitch 20 m/lane-km	m^2	0.02	0.02	0.02

Pavement layer / treatment	Unit	Unit rate ($)		
		Small-scale	Medium-scale	Large-scale
Rout & seal 10% of cross-stitch 40 m/lane-km	m^2	0.04	0.04	0.04
Routine maintenance	m^2	0.08	0.08	0.08
Continuously Reinforced Concrete Pavements				
Retexturing concrete surface 30% area	m^2	7.17	6.84	6.81
Remove and replace silicon seals at transverse and longitudinal joints	m^2	5.25	5.25	5.25
Remove and replace concrete base 0.5% area	m^2	1.56	1.54	1.54
Remove and replace concrete base 1% area	m^2	3.12	3.09	3.08
Mill 30 mm	m^2	8.86	7.76	7.65
Pave 30 mm OGA	m^2	19.55	16.80	16.53
10 mm PMB seal	m^2	9.99	7.24	6.96
Routine maintenance	m^2	0.04	0.04	0.04

Table C 6: Maintenance costs adopted for Perth region

Pavement layer / treatment	Unit	Unit rate ($)		
		Small-scale	Medium-scale	Large-scale
Flexible pavements				
Mill 30 mm	m^2	5.73	5.47	5.44
Pave 30 mm OGA	m^2	15.16	14.36	14.29
Pave 30 mm DGA10(C170)	m^2	15.16	14.36	14.29
Pave 30 mm DGA10(A15E or A35P)	m^2	17.37	16.57	16.50
Mill 40 mm	m^2	7.64	7.29	7.25
Pave 40 mm DGA14(C320)	m^2	19.92	19.12	19.04
Pave 40 mm DGA14(A15E or A35P)	m^2	22.59	21.79	21.71
Mill 60 mm	m^2	11.46	10.94	10.88
Double/double 14 mm / 7 mm heavy grade fabric geotextile reinforced seal (GRS)	m^2	15.08	9.62	9.52
10 mm SAMI seal	m^2	7.24	6.44	6.36
Mill 60 mm, and place SAMI + DGA10 +OGA	m^2	48.41	46.56	46.38
Mill 60 mm, and place SAMI + DGA10(A15E or A35P) +OGA	m^2	51.08	49.23	49.05
Mill 40 mm DGA, pave 40 mm DGA14(C320)	m^2	27.08	25.96	25.84
Mill 40 mm DGA, pave 40 mm DGA14(A15E or A35P)	m^2	29.75	28.63	28.51
Mill 30 mm DGA, place GRS, pave 30 mm DGA10(C170)	m^2	31.95	30.10	29.91
Mill 30 mm DGA, place GRS, pave 30 mm DGA10(A15E or A35P)	m^2	34.62	32.77	32.58
Mill 40 mm DGA, place GRS, pave 40 mm DGA14(C320)	m^2	34.78	32.84	32.64
Mill 40 mm DGA, place GRS, pave 40 mm DGA14(A15E or A35P)	m^2	37.45	35.51	35.31
Mill 60 mm, place GRS, pave 30 mm DGA10 + 30 mm OGA	m^2	53.09	51.18	50.99
Mill 60 mm, place GRS, pave 30 mm DGA10(A15E or A35P) + 30 mm OGA	m^2	55.30	53.39	53.20

Pavement layer / treatment	Unit	Unit rate ($)		
		Small-scale	Medium-scale	Large-scale
Mill 70 mm, place SAMI, pave 40 mm DGA14 + 30 mm OGA	m^2	51.24	49.30	49.11
Mill 70 mm, place SAMI, pave 40 mm DGA14(A15E or A35P) + 30 mm OGA	m^2	53.91	51.97	51.78
Heavy patching over 1% of area	m^2	1.39	1.39	1.39
Routine maintenance	m^2	0.29	0.29	0.29
Plain concrete pavements				
Retexturing concrete surface 30% area	m^2	5.27	5.20	5.19
Remove and replace silicon seals of transverse and longitudinal joints	m^2	8.76	8.76	8.76
Remove and replace concrete base slabs 0.5% area	m^2	1.31	1.30	1.30
Remove and replace concrete base and subbase	m^2	1.57	1.56	1.56
Cross-stitch plain concrete pavements 20 m/lane-km	m^2	1.11	0.98	0.95
Cross-stitch plain concrete pavements 40 m/lane-km	m^2	2.22	1.95	1.90
Rout & seal 10% of cross-stitch 20 m/lane-km	m^2	0.01	0.01	0.01
Rout & seal 10% of cross-stitch 40 m/lane-km	m^2	0.02	0.02	0.02
Routine maintenance	m^2	0.08	0.08	0.08
Continuously reinforced concrete pavements				
Retexturing concrete surface 30% area	m^2	5.27	5.20	5.19
Remove and replace silicon seals at transverse and longitudinal joints	m^2	3.00	3.00	3.00
Remove and replace concrete base 0.5% area	m^2	1.31	1.30	1.30
Remove and replace concrete base 1% area	m^2	2.61	2.60	2.60
Mill 30 mm	m^2	8.86	7.76	7.65
Pave 30 mm OGA	m^2	19.55	16.80	16.53
10 mm PMB seal	m^2	7.24	6.44	6.36
Routine maintenance	m^2	0.04	0.04	0.04

Table C 7: Maintenance costs adopted for Port Hedland region

Pavement layer / treatment	Unit	Unit rate ($)		
		Small-scale	Medium-scale	Large-scale
Flexible pavements				
Mill 30 mm	m^2	18.58	10.01	9.16
Pave 30 mm OGA	m^2	57.10	31.41	28.84
Pave 30 mm DGA10(C170)	m^2	57.10	31.41	28.84
Pave 30 mm DGA10(A15E)	m^2	60.04	34.35	31.78
Mill 40 mm	m^2	24.77	13.35	12.21
Pave 40 mm DGA14(C320)	m^2	66.62	40.93	38.36
Pave 40 mm DGA14(A15E or A35P)	m^2	70.18	44.49	41.92
Mill 60 mm	m^2	37.16	20.02	18.32
Double/double 14 mm / 7 mm heavy grade fabric geotextile reinforced seal (GRS)	m^2	55.75	17.36	13.52
10 mm SAMI seal	m^2	37.32	11.62	9.05

Pavement layer / treatment	Unit	Unit rate ($)		
		Small-scale	Medium-scale	Large-scale
Mill 60 mm, and place SAMI + DGA10 +OGA	m^2	150.42	90.46	84.46
Mill 60 mm, and place SAMI + DGA10(A15E or A35P) +OGA	m^2	153.98	94.02	88.02
Mill 40 mm DGA, pave 40 mm DGA14(C320)	m^2	89.85	53.44	49.81
Mill 40 mm DGA, pave 40 mm DGA14(A15E or A35P)	m^2	93.41	57.00	53.37
Mill 30 mm DGA, place GRS, pave 30 mm DGA10(C170)	m^2	117.00	57.04	50.49
Mill 30 mm DGA, place GRS, pave 30 mm DGA10(A15E or A35P)	m^2	120.56	60.60	54.05
Mill 40 mm DGA, place GRS, pave 40 mm DGA14(C320)	m^2	128.65	65.86	59.59
Mill 40 mm DGA, place GRS, pave 40 mm DGA14(A15E or A35P)	m^2	132.21	69.42	63.15
Mill 60 mm, place GRS, pave 30 mm DGA10 + 30 mm OGA	m^2	158.32	96.21	90.00
Mill 60 mm, place GRS, pave 30 mm DGA10(A15E or A35P) + 30 mm OGA	m^2	161.26	99.15	92.94
Mill 70 mm, place SAMI, pave 40 mm DGA14 + 30 mm OGA	m^2	162.07	99.28	93.56
Mill 70 mm, place SAMI, pave 40 mm DGA14(A15E or A35P) + 30 mm OGA	m^2	165.63	102.84	97.12
Heavy patching over 1% of area	m^2	1.39	1.39	1.39
Routine maintenance	m^2	0.29	0.29	0.29
Plain concrete pavements				
Retexturing concrete surface 30% area	m^2	13.75	9.47	9.04
Remove and replace silicon seals of transverse and longitudinal joints	m^2	24.10	24.10	24.10
Remove and replace concrete base slabs 0.5% area	m^2	2.75	2.55	2.53
Remove and replace concrete base and subbase	m^2	3.30	3.06	3.04
Cross-stitch plain concrete pavements 20 m/lane-km	m^2	3.38	1.93	1.66
Cross-stitch plain concrete pavements 40 m/lane-km	m^2	6.76	3.86	3.31
Rout & seal 10% of cross-stitch 20 m/lane-km	m^2	0.03	0.03	0.03
Rout & seal 10% of cross-stitch 40 m/lane-km	m^2	0.06	0.06	0.06
Routine maintenance	m^2	0.08	0.08	0.08
Continuously reinforced concrete pavements				
Retexturing concrete surface 30% area	m^2	13.75	9.47	9.04
Remove and replace silicon seals at transverse and longitudinal joints	m^2	8.25	8.25	8.25
Remove and replace concrete base 0.5% area	m^2	2.75	2.55	2.53
Remove and replace concrete base 1% area	m^2	5.50	5.10	5.06
Mill 30 mm	m^2	8.86	7.76	7.65
Pave 30 mm OGA	m^2	19.55	16.80	16.53
10 mm PMB seal	m^2	37.32	11.62	9.05
Routine maintenance	m^2	0.04	0.04	0.04

Table C 8: Maintenance costs adopted for Broome region

Pavement layer / treatment	Unit	Unit rate ($)		
		Small-scale	Medium-scale	Large-scale
Flexible pavements				
Mill 30 mm	m^2	18.07	9.50	8.65
Pave 30 mm OGA	m^2	54.25	28.55	25.98
Pave 30 mm DGA10(C170)	m^2	54.25	28.55	25.98
Pave 30 mm DGA10(A15E)	m^2	57.38	31.68	29.11
Mill 40 mm	m^2	24.09	12.67	11.53
Pave 40 mm DGA14(C320)	m^2	62.82	37.12	34.55
Pave 40 mm DGA14(A15E or A35P)	m^2	66.60	40.90	38.33
Mill 60 mm	m^2	36.14	19.00	17.30
Double/double 14 mm / 7 mm heavy grade fabric geotextile reinforced seal (GRS)	m^2	55.08	16.69	12.85
10 mm SAMI seal	m^2	36.87	11.17	8.60
Mill 60 mm, and place SAMI + DGA10 +OGA	m^2	144	84.19	78.20
Mill 60 mm, and place SAMI + DGA10(A15E or A35P) +OGA	m^2	148	87.97	81.98
Mill 40 mm DGA, pave 40 mm DGA14(C320)	m^2	85.41	49.00	45.36
Mill 40 mm DGA, pave 40 mm DGA14(A15E or A35P)	m^2	89.19	52.78	49.14
Mill 30 mm DGA, place GRS, pave 30 mm DGA10(C170)	m^2	113	53.19	47.20
Mill 30 mm DGA, place GRS, pave 30 mm DGA10(A15E or A35P)	m^2	117	56.97	50.98
Mill 40 mm DGA, place GRS, pave 40 mm DGA14(C320)	m^2	124	60.93	54.65
Mill 40 mm DGA, place GRS, pave 40 mm DGA14(A15E or A35P)	m^2	128	64.71	58.43
Mill 60 mm, place GRS, pave 30 mm DGA10 + 30 mm OGA	m^2	152	89.82	83.61
Mill 60 mm, place GRS, pave 30 mm DGA10(A15E or A35P) + 30 mm OGA	m^2	155	92.95	86.74
Mill 70 mm, place SAMI, pave 40 mm DGA14 + 30 mm OGA	m^2	155	91.93	85.65
Mill 70 mm, place SAMI, pave 40 mm DGA14(A15E or A35P) + 30 mm OGA	m^2	158	95.71	89.43
Heavy patching over 1% of area	m^2	1.39	1.39	1.39
Routine maintenance	m^2	0.29	0.29	0.29

Pavement layer / treatment	Unit	Unit rate ($)		
		Small-scale	Medium-scale	Large-scale
Plain concrete pavements				
Retexturing concrete surface 30% area	m^2	13.45	9.16	8.74
Remove and replace silicon seals of transverse and longitudinal joints	m^2	23.22	23.22	23.22
Remove and replace concrete base slabs 0.5% area	m^2	3.06	2.86	2.84
Remove and replace concrete base and subbase	m^2	3.67	3.43	3.40
Cross-stitch plain concrete pavements 20 m/lane-km	m^2	3.33	1.88	1.61
Cross-stitch plain concrete pavements 40 m/lane-km	m^2	6.66	3.76	3.22
Rout & seal 10% of cross-stitch 20 m/lane-km	m^2	0.03	0.03	0.03
Rout & seal 10% of cross-stitch 40 m/lane-km	m^2	0.06	0.06	0.06
Routine maintenance	m^2	0.08	0.08	0.08
Continuously reinforced concrete pavements				
Retexturing concrete surface 30% area	m^2	13.45	9.16	8.74
Remove and replace silicon seals at transverse and longitudinal joints	m^2	7.95	7.95	7.95
Remove and replace concrete base 0.5% area	m^2	3.06	2.86	2.84
Remove and replace concrete base 1% area	m^2	6.11	5.71	5.67
Mill 30 mm	m^2	8.86	7.76	7.65
Pave 30 mm OGA	m^2	19.55	16.80	16.53
10 mm PMB seal	m^2	36.87	11.17	8.60
Routine maintenance	m^2	0.04	0.04	0.04

APPENDIX D EXAMPLES OF INITIAL CONSTRUCTION COSTS

This Appendix contains examples of initial construction costs.

D.1 Bunbury Region

D.1.1 Freeways

Figure D 1 and Figure D 2 show examples of the initial construction costs for Bunbury freeways based on unit rates for large-scale works. The surfacing comprises an open graded asphalt wearing course with one of the following:

- 30 mm thick size 10 dense graded asphalt with C170 bitumen (P1b, P1c, P1d)
- 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen (P2, P3 and P4) or
- continuously reinforced concrete base (P6a).

As expected for more lightly loaded freeways (< 5 x 10^7) expected in the Bunbury region, thin asphalt surfaced HCTCRB pavements are clearly the lowest in cost. For the case of a subgrade design CBR of 3%, HCTCRB with granular subbase (P1b) is lower in cost.

Note that HCTCRB is yet to be produced in the Bunbury region. Until such time as it is produced, full-depth asphalt pavement (P2) will have the lowest cost.

The CRCP concrete pavement with open graded asphalt surfacing (P6a) has clearly the highest cost.

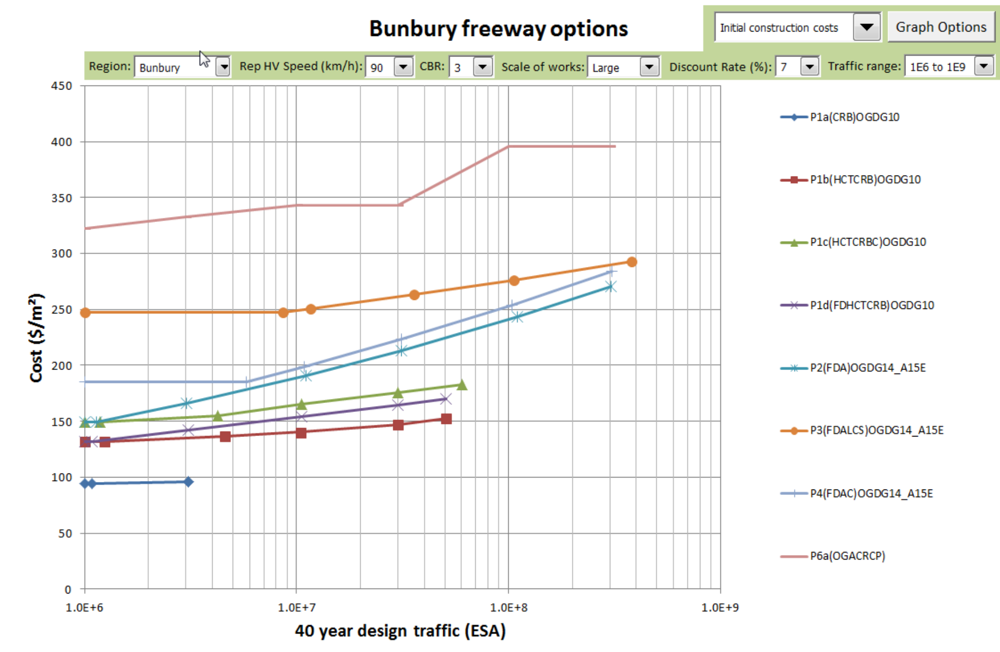

Figure D 1: Initial construction costs for Bunbury region freeways, open graded asphalt surfacing, subgrade design CBR = 3% and design speed 90 km/h

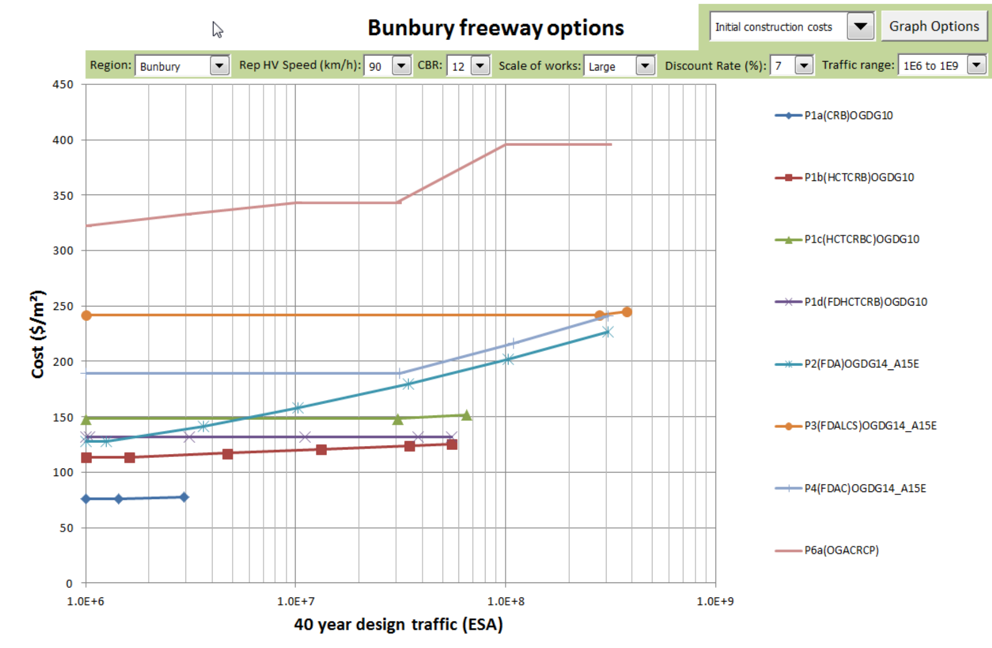

Figure D 2: Initial construction costs for Bunbury region freeways, open graded asphalt surfacing, subgrade design CBR = 12% and design speed 90 km/h

D.1.2 Arterial roads

Figure D 3 and Figure D 4 are examples of the calculated initial construction costs for Bunbury region arterial roads based on unit rates for medium-scale works. Except for the concrete pavement options, the wearing course is either:

- 30 mm thick size 10 dense graded asphalt with C170 bitumen (P1a, P1b, P1c, P1d) or
- 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen (P2, P3 and P4).

Figure D 3 and Figure D 4 indicate that thin asphalt surfaced crushed rock base pavements (P1a) have the lowest initial cost for Bunbury arterial roads. However, for 40 year design traffic loading exceeding about 4 x 10^6 ESA, this pavement type has insufficient asphalt fatigue. In such cases, thin asphalt surfaced HCTCRB pavements (P1b, P1d) are the lowest in cost.

Note that HCTCRB is yet to be produced in the Bunbury region. Until such time as it is produced, full-depth asphalt pavement (P2) will have the lowest cost.

The two concrete pavement types (P5 and P6) are clearly higher in cost.

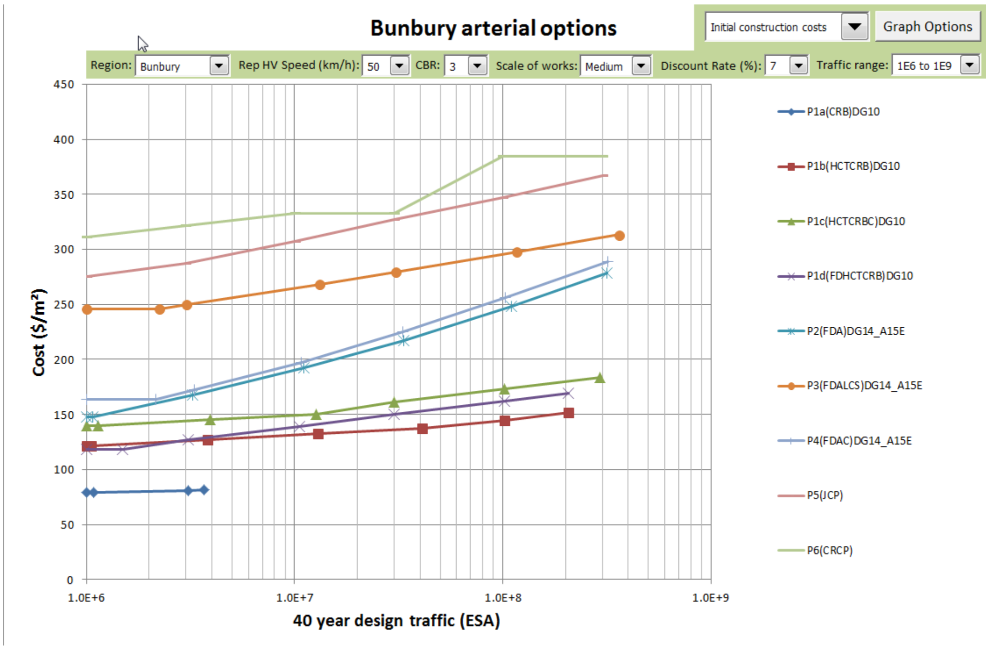

Figure D 3: Initial construction costs for Bunbury region arterial roads, dense graded asphalt surfacing, subgrade design CBR = 3% and design speed 50 km/h

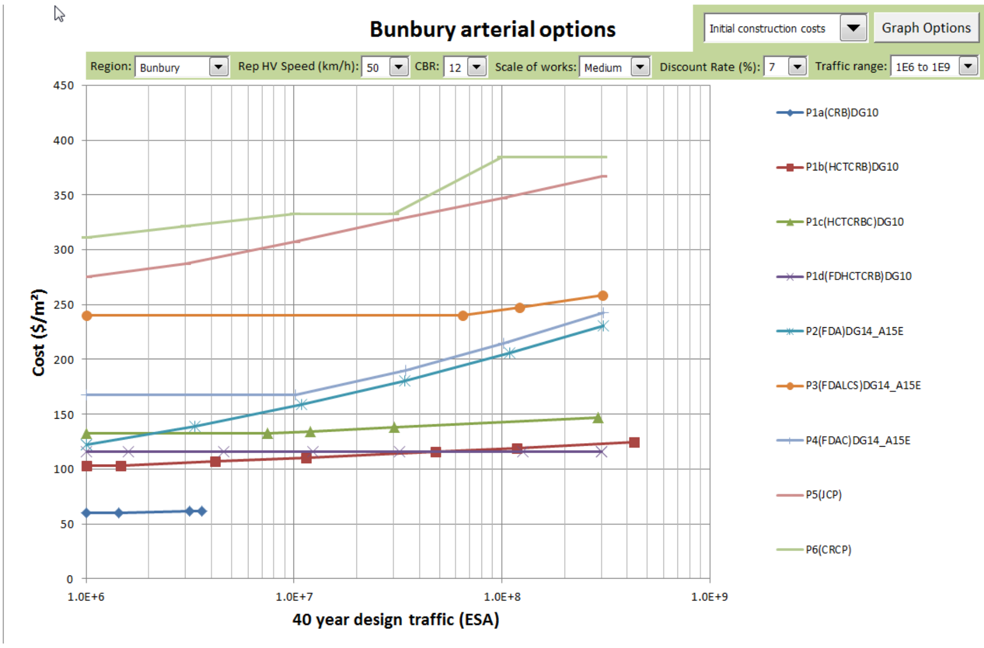

Figure D 4: Initial construction costs for Bunbury region arterial roads, dense graded asphalt surfacing, subgrade design CBR = 12% and design speed 50 km/h

D.1.3 Signalised intersections

Figure D 5 and Figure D 6 are examples of the calculated initial construction costs for Bunbury signalised intersections based on unit rates for small-scale works. Except for the concrete pavement options, the wearing course is 40 mm thick size 14 dense graded asphalt using an A15E polymer modified C320 bitumen.

The cost rankings are similar to those for Bunbury arterials. Figure D 5 and Figure D 6 indicate that the full-depth asphalt or deep strength asphalt pavements (P2, P4) are the lowest in cost as thin asphalt surfaced crushed rock baser pavements have inadequate asphalt fatigue life.

The two concrete pavement types (P5 and P6) and the thick asphalt on lean concrete subbase (P3) are clearly higher in cost.

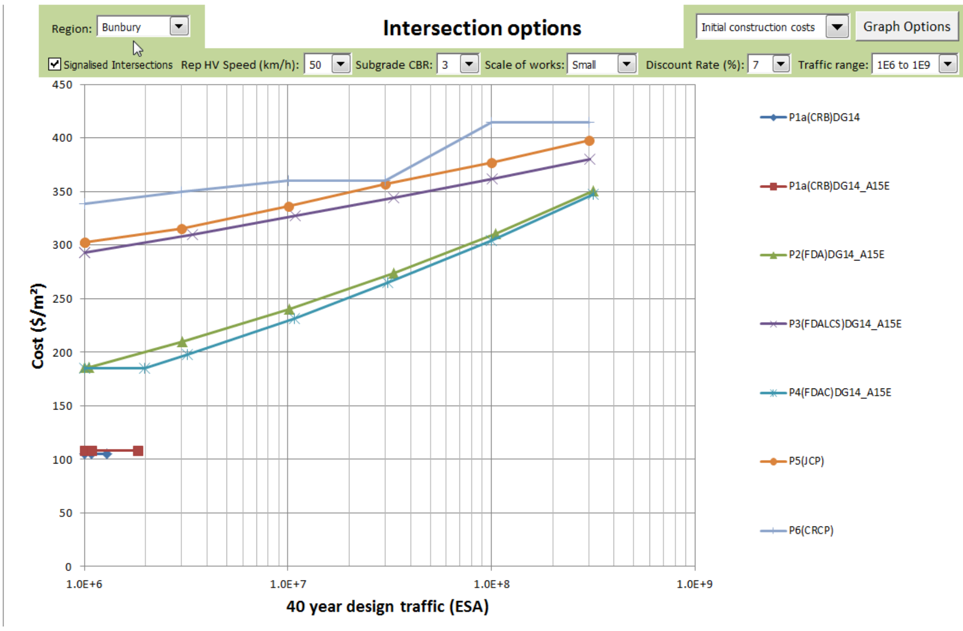

Figure D 5: Initial construction costs for Bunbury region signalised intersections, dense graded asphalt surfacing, subgrade design CBR = 3%

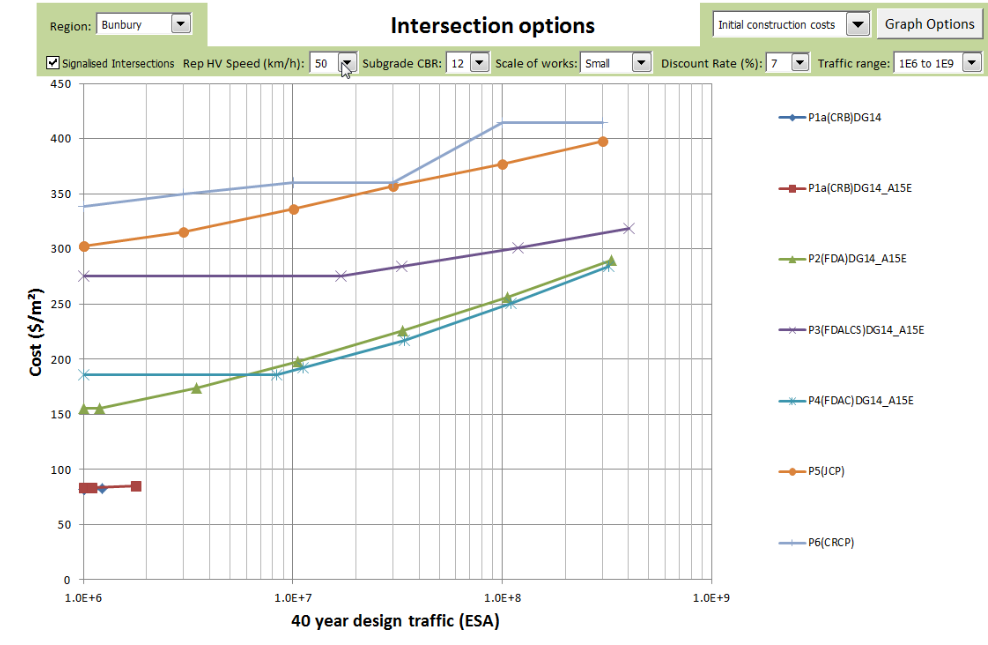

Figure D 6: Initial construction costs for Bunbury region signalised intersections, dense graded asphalt surfacing, subgrade design CBR = 12%

D.2 Perth Region

D.2.1 Freeways

Figure D 7 and Figure D 8 are examples of the calculated initial construction costs for Perth freeways based on unit rates for large-scale works. The surfacing comprises an open graded asphalt wearing course with one of the following:

- 30 mm thick size 10 dense graded asphalt with C170 bitumen (P1a, P1a5, P1b, P1c, P1d)
- 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen (P2, P3 and P4) or
- continuously reinforced concrete base (P6a).

As expected for more lightly loaded freeways (< 8 x 10^7 ESA), thin asphalt surfaced granular pavements with HCTCRB are clearly the lowest in cost. For the common case of a subgrade design CBR of 12%, Figure D 8 indicates full-depth HCTCRB (P1d) is lower in cost when the HCTCRB is supported with crushed limestone subbase (P1b) or cement treated crushed rock (P1c).

For freeways where the 40 year design traffic loading exceeds the maximum allowable loading (about 8 x 10^7 ESA) of thin asphalt surfaced HCTCRB pavements, the full-depth asphalt (P2) or deep strength asphalt (P4) pavements are the lowest options.

The concrete pavement (P6a) is clearly the highest cost.

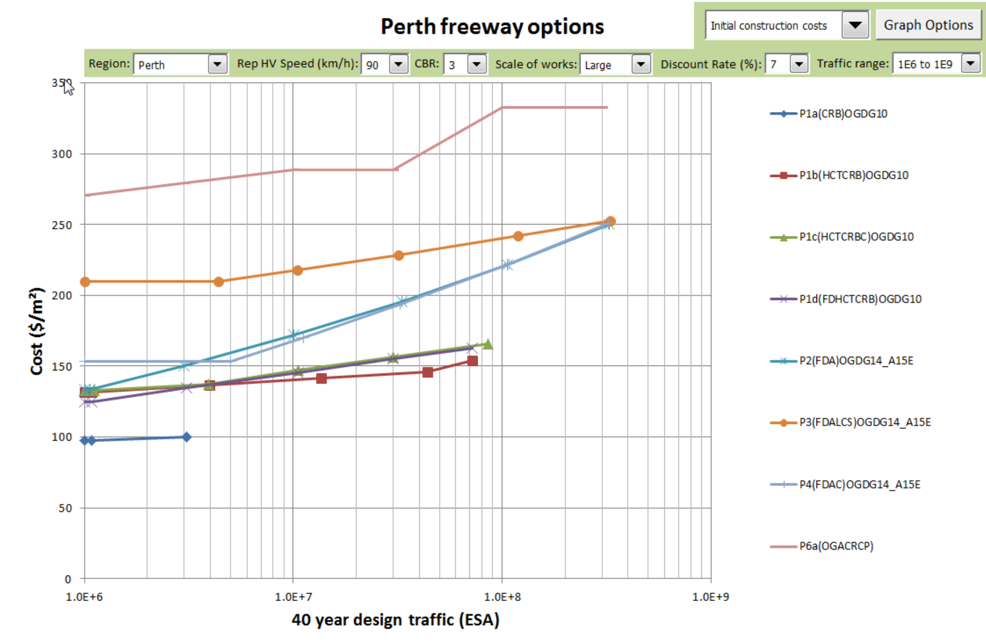

Figure D 7: **Initial construction costs for Perth region freeways with open graded asphalt surfacing, subgrade design CBR = 3% and design speed 90 km/h**

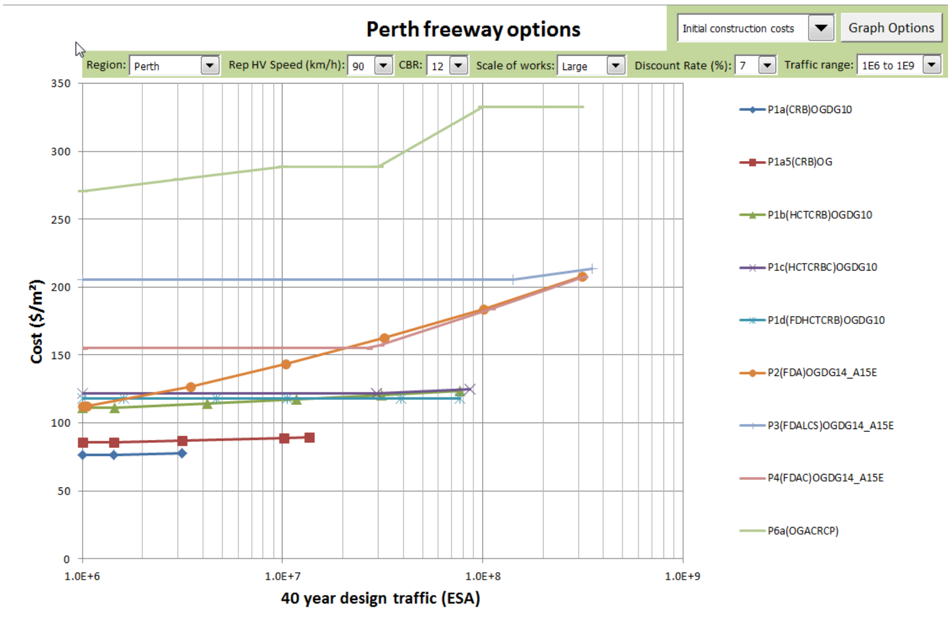

Figure D 8: **Initial construction costs for Perth region freeways with open graded asphalt surfacing, subgrade design CBR = 12% and design speed 90 km/h**

D.2.2 Arterial Roads

Figure D 9 and Figure D 10 are examples of the initial construction costs for Perth arterial roads based on unit rates for medium-scale works. Except for the concrete pavement options (which have no wearing course), the wearing course was either:

- 30 mm thick size 10 dense graded asphalt with C170 bitumen on granular pavements (P1a, P1a5, P1b, P1c, P1d); or

- 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen on full-depth asphalt, flexible composite or deep strength asphalt pavement (P2, P3 and P4)

As part of the project, Main Roads WA requested evaluation of Pavement Type 1a5, thin asphalt surfaced crushed rock base pavement designed with a 5 year asphalt fatigue life rather than the current practice of specifying a 15 year fatigue life. Figure D 9 and Figure D 10 indicate that asphalt on crushed rock base (Types P1a and P1a5) have the lowest construction cost for Perth arterial roads. For commonly used subgrade design CBR of 12% (sand), the maximum allowable traffic loading over 40 years of thin asphalt surface granular pavements with 5 year fatigue life (P1a5) is about 3 x 10^7 ESA. For more heavily trafficked arterials, thin asphalt on full-depth HCTCRB (P1d) has the lowest cost.

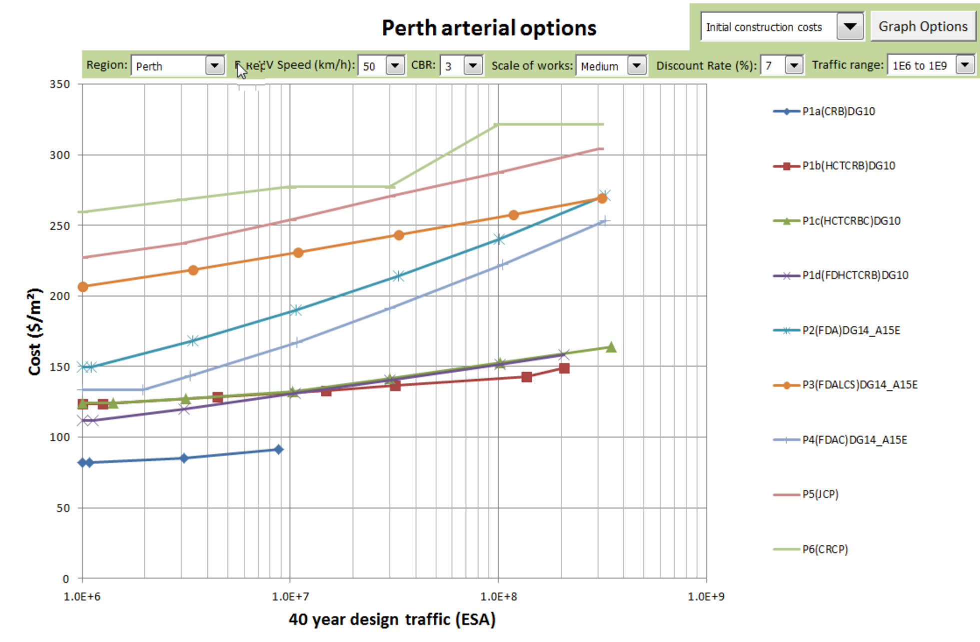

Figure D 9: **Initial construction costs for Perth region arterial roads with dense graded asphalt surfacing, subgrade design CBR = 3% and design speed 50 km/h**

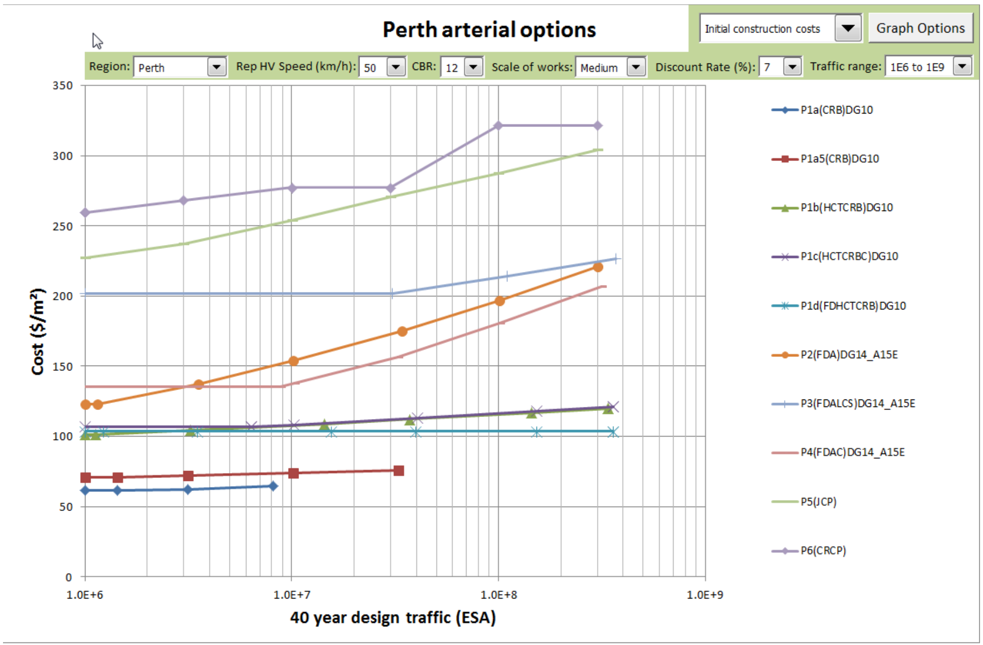

Figure D 10: Initial construction costs for Perth region arterial roads with dense graded asphalt surfacing, subgrade design CBR = 12% and design speed 50 km/h

D.2.3 Perth Signalised Intersections

Figure D 11 and Figure D 12 are examples of the construction costs for Perth intersections based on unit rates for small-scale works. Except for the concrete pavement options, the wearing course is 40 mm thickness of size 14 dense graded asphalt using A15E polymer modified C320 bitumen. Note that designs are not provided for HCTCRB pavements as the inclusion of the geotextile reinforced seal to reduce the risk of reflection cracking results in this pavement type being unsuitable for the high shear stresses at signalised intersections.

Figure D 11 and Figure D 12 indicate that thin asphalt surfaced crushed rock base pavements (P1a and P1a5) have the lowest construction costs. Note that although Main Roads WA ERN9 requires the use of polymer modified binder A15E at intersections for rut-resistance, no allowance is made for the calculated increase in fatigue life due its lower modulus. For commonly used subgrade design CBR of 12% (sand), the maximum allowable traffic loading over 40 years of thin asphalt surface granular pavements with 5 year fatigue life (P1a5) is about 8 x 10^6 ESA. For higher traffic loadings, thick asphalt on cement treated crushed rock subbase pavements (P4) are the lowest cost.

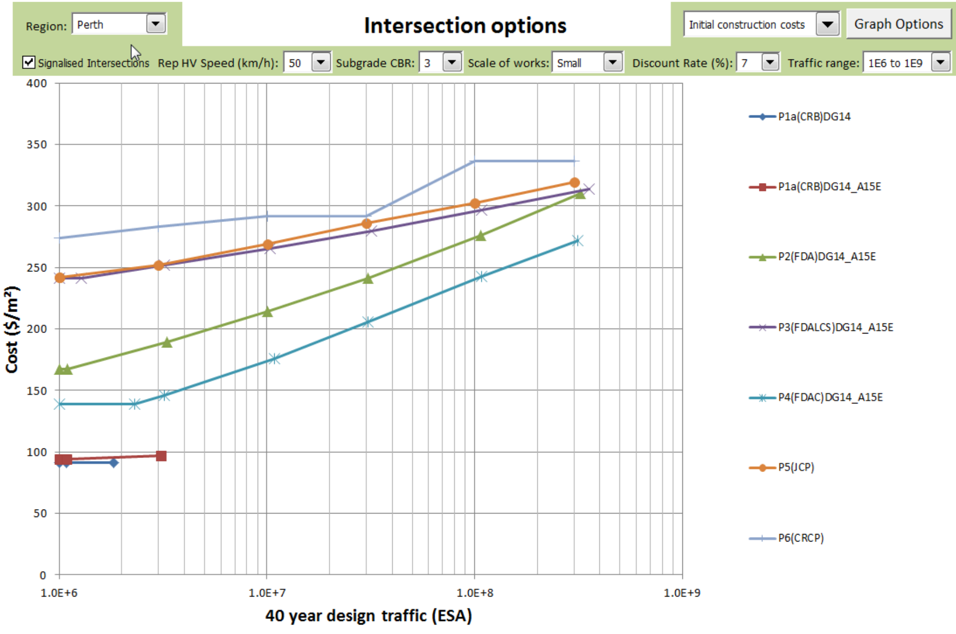

Figure D 11: Initial construction costs for Perth region signalised intersections, subgrade design CBR = 3%

Figure D 12: Initial construction costs for Perth region signalised intersections, subgrade design CBR = 12%

D.3 Port Hedland Region

D.3.1 Freeways

Figure D 13 and Figure D 14 are examples of the calculated initial construction costs for Port Hedland freeways based on unit rates for large-scale works. The surfacing comprises an open graded asphalt wearing course with one of the following:

- 30 mm thick size 10 dense graded asphalt with C170 bitumen (P1a, P1b, P1c, P1d)

- 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen (P2, P3 and P4) or
- continuously reinforced concrete base (P6a).

As expected, thin asphalt surfaced HCTCRB pavements (P1b, P1d) are clearly the lowest in cost.

Note that HCTCRB is yet to be produced in the Port Hedland region. Until such time as it is produced, either full-depth asphalt pavement (P2) or deep strength asphalt pavement (P4) have the lowest cost.

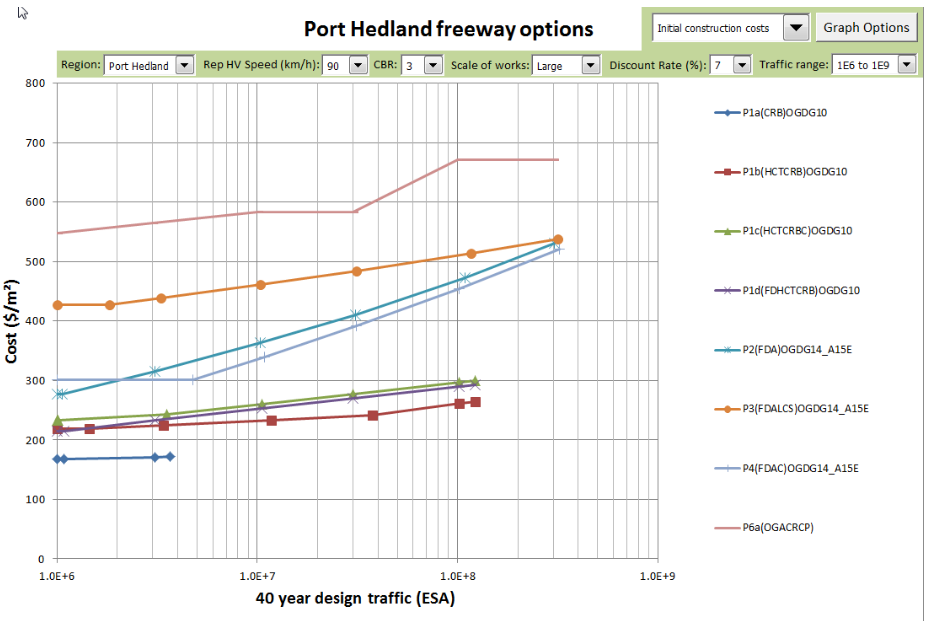

Figure D 13: Initial construction costs for Port Hedland freeways with open graded asphalt surfacing, subgrade design CBR = 3% and design speed 90 km/h

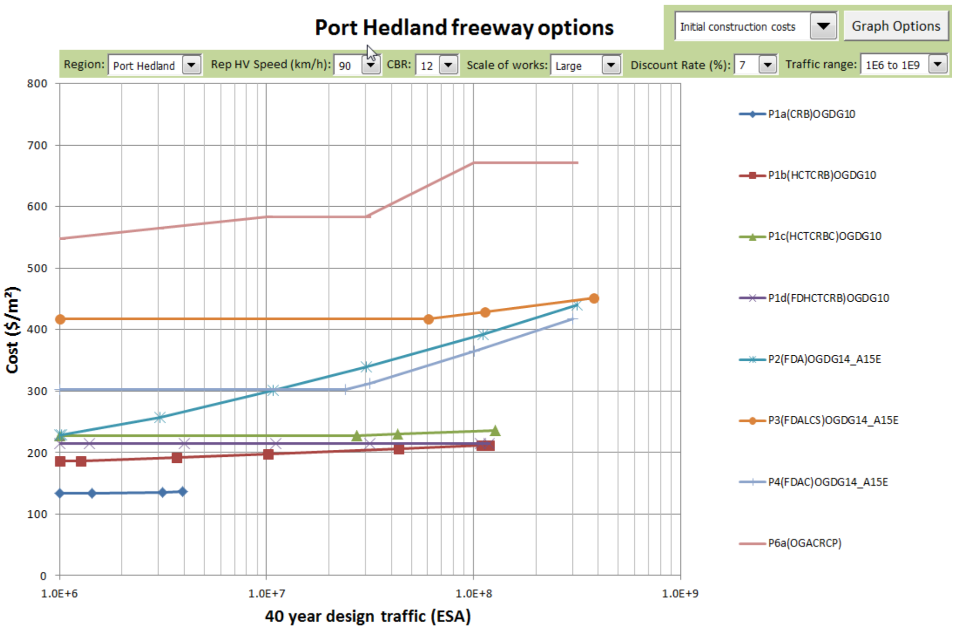

Figure D 14: Initial construction costs for Port Hedland freeways with open graded asphalt surfacing, subgrade design CBR = 12% and design speed 90 km/h

D.3.2 Arterial roads

Figure D 15 and Figure D 16 are examples of the calculated initial construction costs for Port Hedland arterial roads based on unit rates for medium-scale works. Except for the concrete pavement options, the wearing course is either:

- 30 mm thick size 10 dense graded asphalt with C170 bitumen (P1a, P1b, P1c, P1d) or
- 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen (P2, P3 and P4)

Figure D 15 and Figure D 16 indicate that thin asphalt surfaced crushed rock base pavements (P1a) have the lowest initial cost for Port Hedland arterial roads up to a 40 year design traffic loading of 3 x 10^7 ESA. At higher loadings, thin asphalt surfaced HCTCRB pavements (P1b, P1d) are the lowest in cost.

Note that HCTCRB is yet to be produced in the Port Hedland region. Until such time as it is produced, either full-depth asphalt pavement (P2) or deep strength asphalt pavement (P4) have the lowest cost.

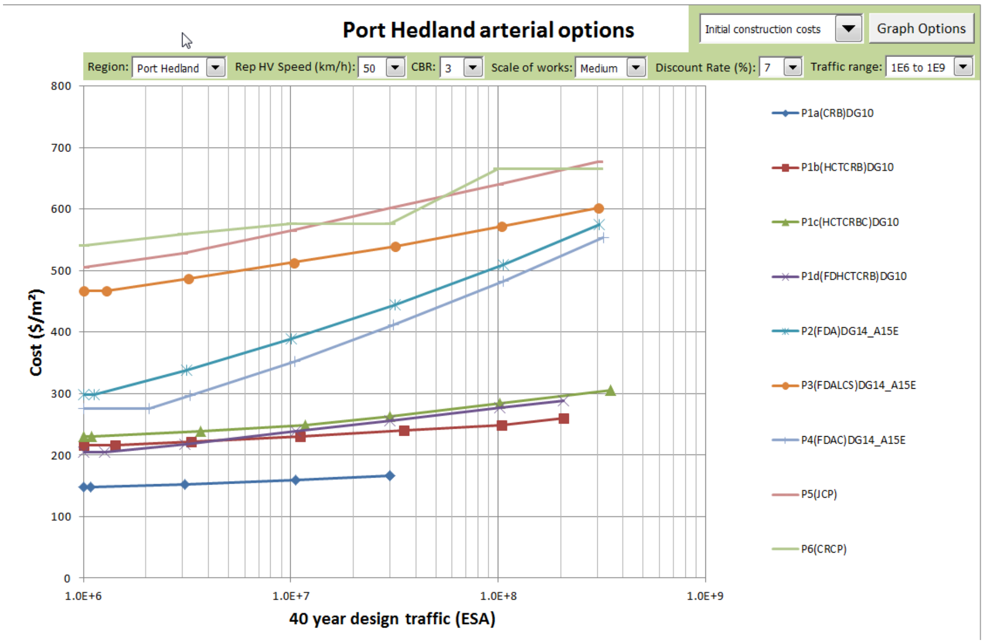

Figure D 15: Initial construction costs for Port Hedland arterial roads with dense graded asphalt surfacing, subgrade design CBR = 3% and design speed 50 km/h

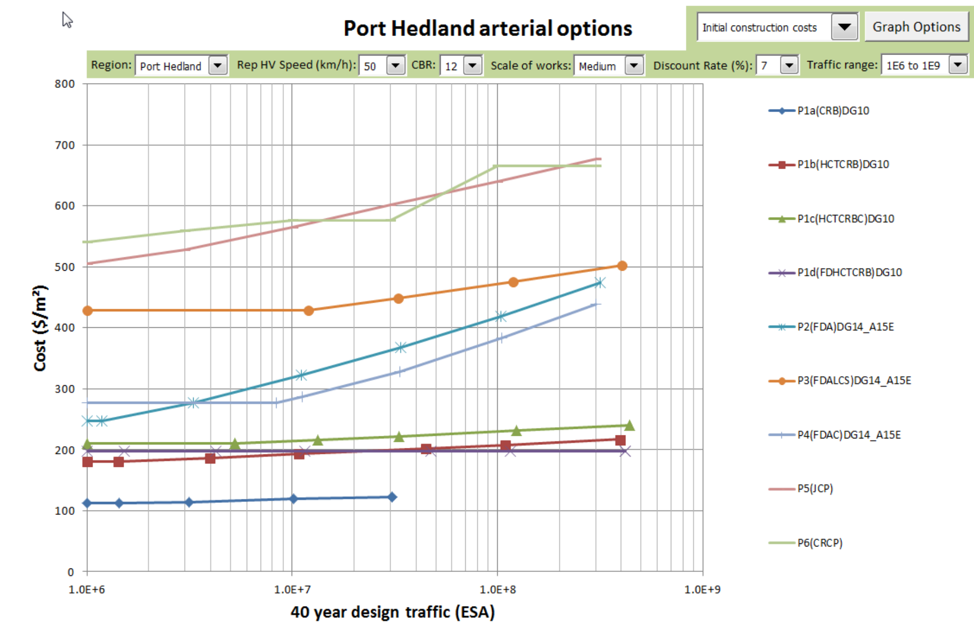

Figure D 16: Initial construction costs for Port Hedland arterial roads with dense graded asphalt surfacing, subgrade design CBR = 12% and design speed 50 km/h

D.3.3 Signalised intersections

Figure D 17 and Figure D 18 are examples of the calculated initial construction costs for Port Hedland signalised intersections based on unit rates for small-scale works. Except for the concrete pavement options, the wearing course is 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen.

The cost rankings are similar to those for Port Hedland arterials. Figure D 17 and Figure D 18 indicate that thin asphalt surfaced crushed rock base pavements (P1a) have the lowest initial cost for Port Hedland signalised intersection. However, the maximum allowable loading of the 40 mm thick asphalt surfacing is low, about 10^7 ESA. Deep strength asphalt (P4) pavements are clearly the next lowest in cost.

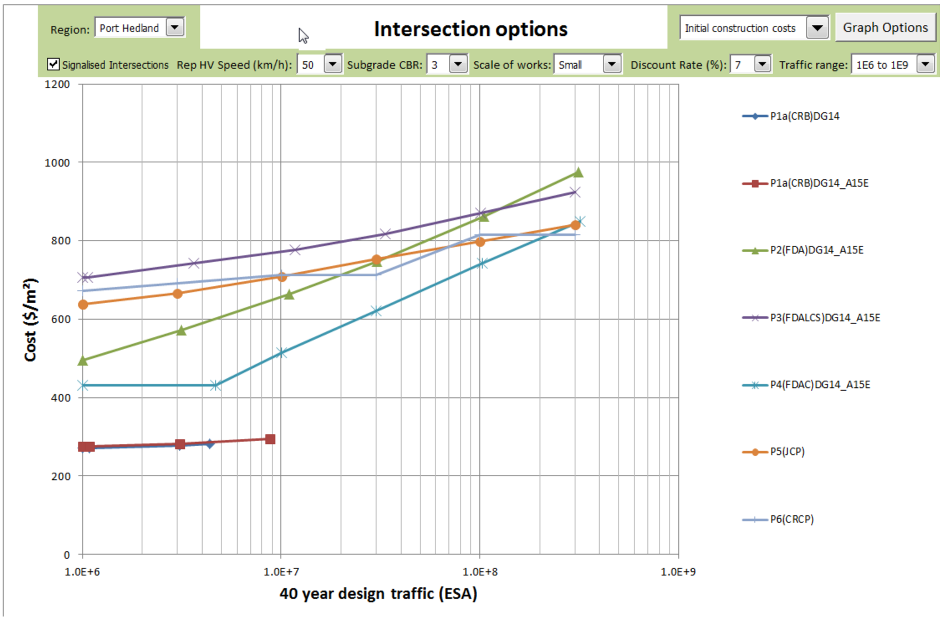

Figure D 17: Initial construction costs for Port Hedland region signalised intersections with dense graded asphalt surfacing, subgrade design CBR = 3%

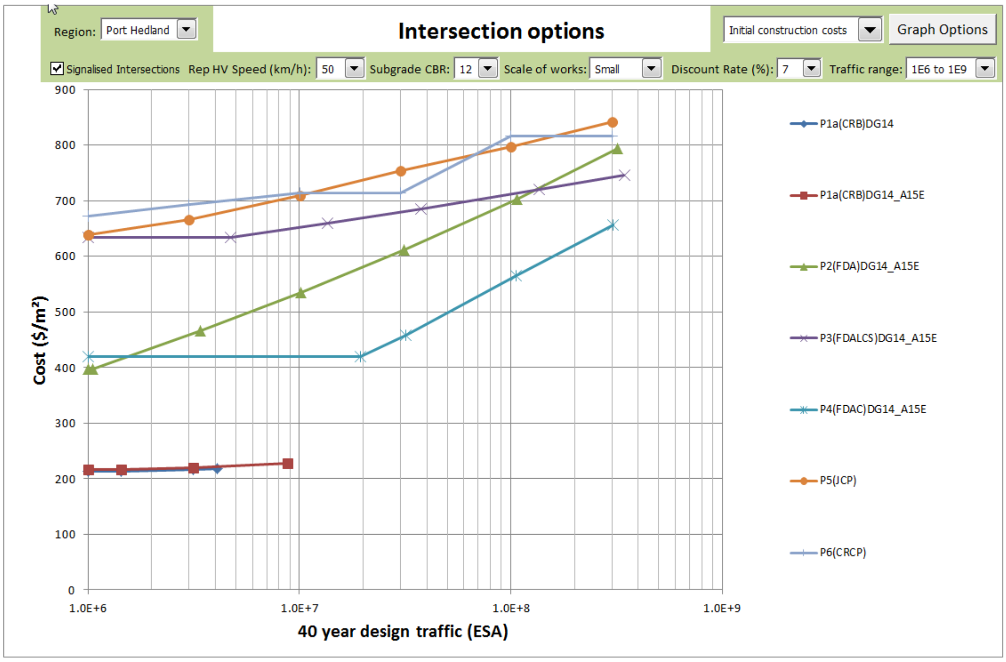

Figure D 18: Initial construction costs for Port Hedland region signalised intersections with dense graded asphalt surfacing, subgrade design CBR = 12%

D.4 Broome Region

D.4.1 Freeways

Figure D 19 and Figure D 20 are examples of the calculated initial construction costs for Broome freeways based on unit rates for large-scale works. The surfacing comprises an open graded asphalt wearing course with one of the following:

- 30 mm thick size 10 dense graded asphalt with C170 bitumen (P1a, P1b, P1c, P1d)
- 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen (P2, P3 and P4) or
- continuously reinforced concrete base (P6a)

As expected, thin asphalt surfaced HCTCRB pavements (P1b and P1d) are clearly the lowest in cost. Note that HCTCRB is yet to be produced in the Broome region. Until such time as it is produced, deep strength asphalt pavements (P4) have the lowest cost.

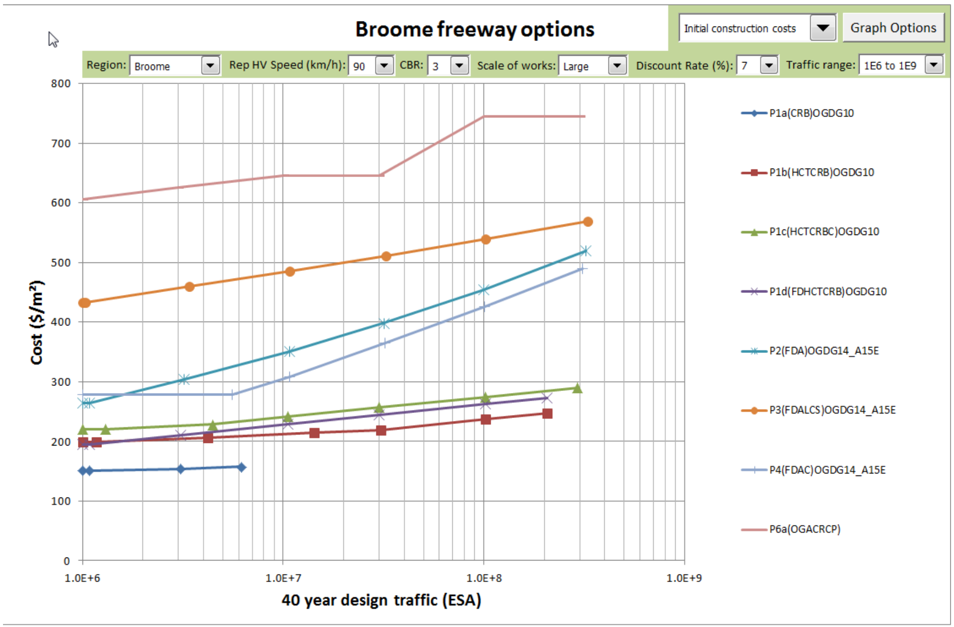

Figure D 19: Initial construction costs for Broome region freeways with open graded asphalt surfacing, subgrade design CBR = 3% and design speed 90 km/h

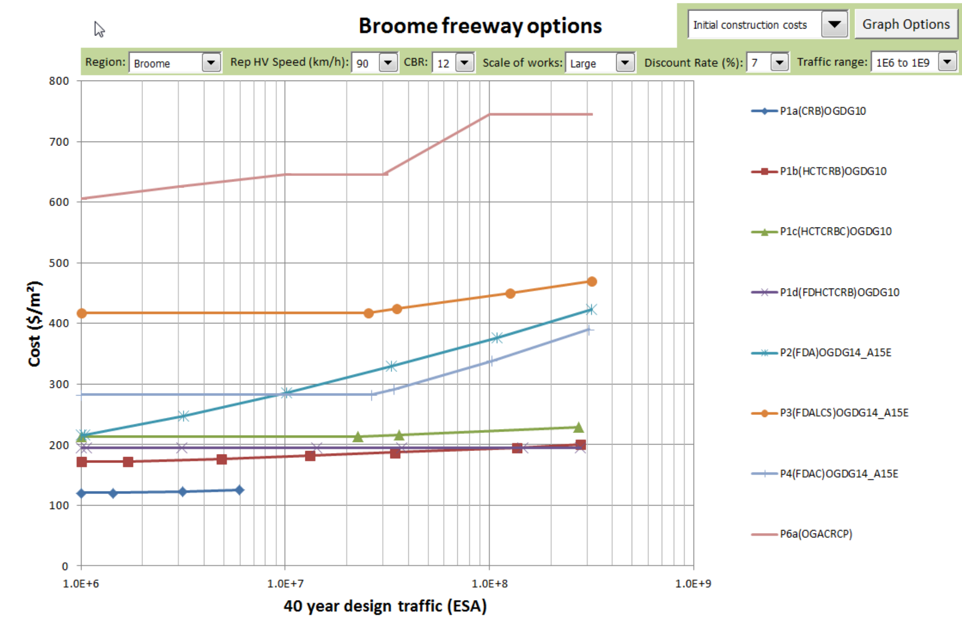

Figure D 20: Initial construction costs for Broome region freeways with open graded asphalt surfacing, subgrade design CBR = 12% and design speed 90 km/h

D.4.2 Arterial Roads

Figure D 21 and Figure D 22 are examples of the calculated initial construction costs for Broome arterial roads based on unit rates for medium-scale works. Except for the concrete pavement options, the wearing course is either:

- 30 mm thick size 10 dense graded asphalt with C170 bitumen (P1a, P1b, P1c, P1d) or

- 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen (P2, P3 and P4)

Figure D 21 and Figure D 22 indicate that thin asphalt surfaced crushed rock base pavements (P1a) have the lowest initial cost for Broome arterial roads.

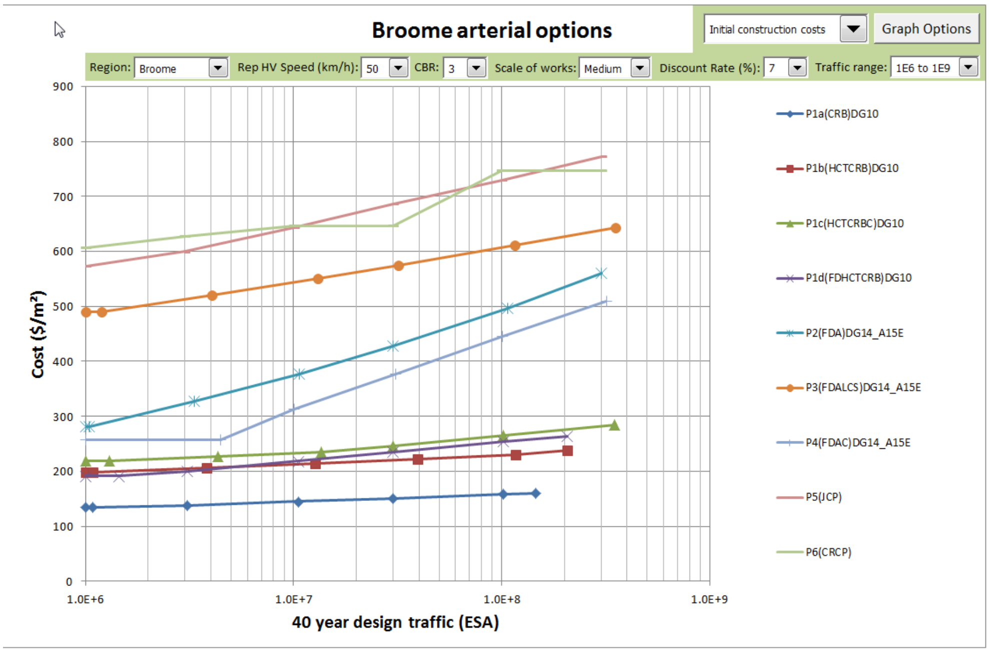

Figure D 21: Initial construction costs for Broome region arterial roads with dense graded asphalt surfacing, subgrade design CBR = 3% and design speed 50 km/h

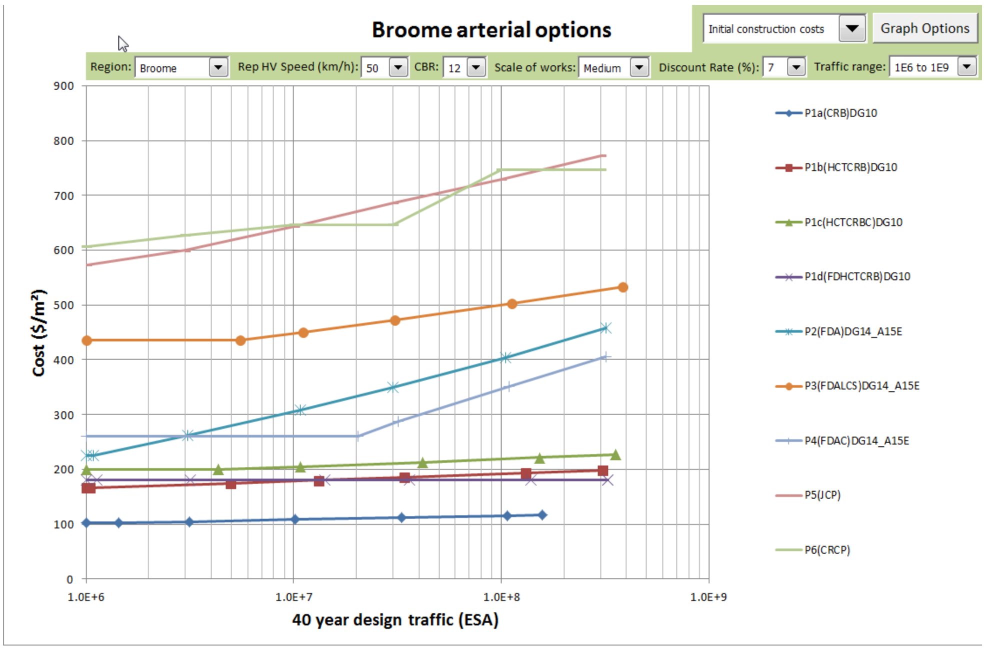

Figure D 22: Initial construction costs for Broome region arterial roads with dense graded asphalt surfacing, subgrade design CBR = 12% and design speed 50 km/h

D.4.3 Signalised intersections

Figure D 23 and Figure D 24 are examples of the calculated initial construction costs for Broome signalised intersections based on unit rates for small-scale works. Except for the concrete pavement options, the wearing course is 40 mm thick size 14 dense graded asphalt (A15E polymer modified C320 bitumen).

The cost rankings are similar to those for Broome arterials. Figure D 23 and Figure D 24 indicate that thin asphalt surfaced crushed rock base pavements (P1a) have the lowest initial cost for Broome signalised intersections. However, the maximum allowable loading of the 40 mm thick asphalt surfacing is low, about 2 x 10^7 ESA. Deep strength asphalt pavement (P4) clearly has the next lowest cost.

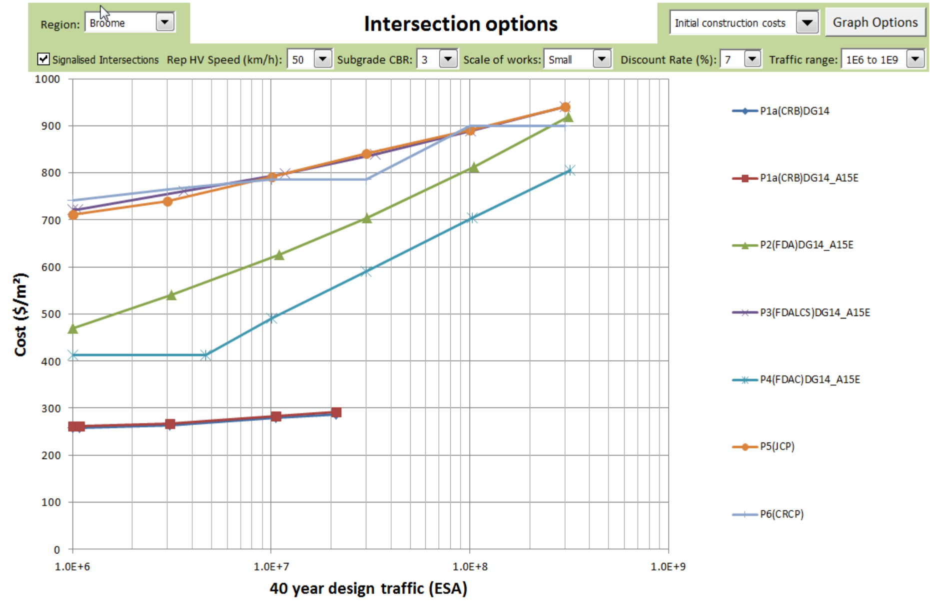

Figure D 23: Initial construction costs for Broome region signalised intersections with dense graded asphalt surfacing, subgrade design CBR = 3%

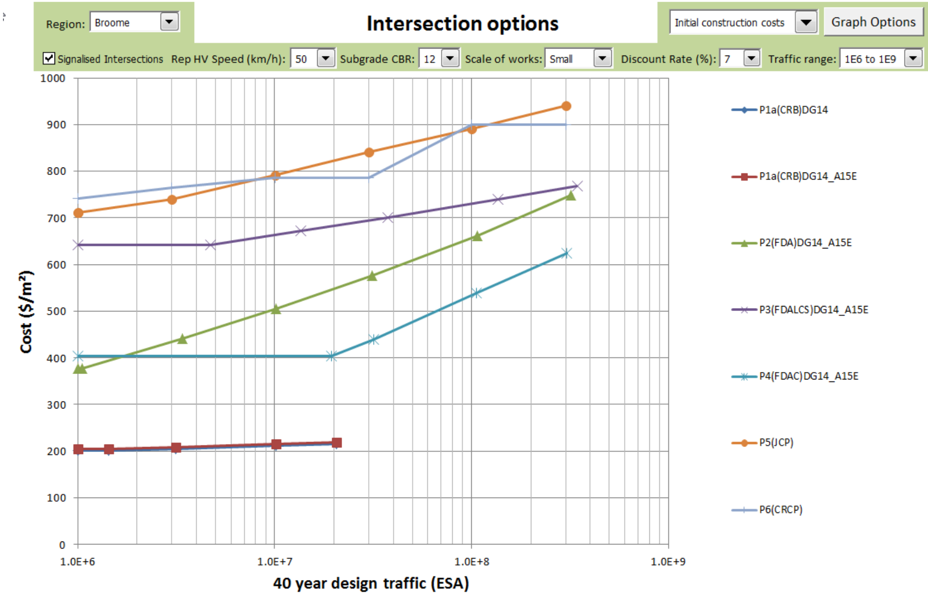

Figure D 24: Initial construction costs for Broome region signalised intersections with dense graded asphalt surfacing, subgrade design CBR = 12%

APPENDIX E DISCOUNTED MAINTENANCE COSTS

Table E 1 to Table E 4 list the discounted maintenance costs calculated with a discount rate of 7% for the four regions.

Table E 1: Discounted maintenance costs Bunbury region

Pavement type	Surface description	DGA with C170 or C320 bitumen			DGA with polymer modified C170 or C320 bitumen		
		Small-scale $/m²	Medium-scale $/m²	Large-scale $/m²	Small-scale $/m²	Medium-scale $/m²	Large-scale $/m²
1a	30 mm DGA	50	45	45	52	47	46
	40 mm DGA (mid block)	54	49	48	56	50	100
	40 mm DGA (intersections)	103	93	92	106	95	94
	30 mm OGA on 30 mm DGA	109	98	97	111	100	99
1b, 1c and 1d	30 mm DGA	145	128	126	148	131	130
	40 mm DGA (mid block or intersections)	151	133	131	154	137	135
	30 mm OGA on 30 mm DGA	179	161	160	182	165	163
2, 3 and 4	40 mm DGA (mid block)	54	49	48	56	50	50
	40 mm DGA (intersections)	102	92	91	105	95	94
	30 mm OGA on 30 mm DGA	112	101	100	114	103	102
5	Plain concrete pavement (PCP)	27	27	26	27	27	26
6	Continuously reinforced concrete pavement (CRCP)	10	10	10	10	10	10
6a	30 mm OGA	45	38	38	45	38	38

Table E 2: Discounted maintenance costs Perth region

Pavement type	Surface description	DGA with C170 or C320 bitumen			DGA with polymer modified C170 or C320 bitumen		
		Small-scale $/m²	Medium-scale $/m²	Large-scale $/m²	Small-scale $/m²	Medium-scale $/m²	Large-scale $/m²
1a	30 mm DGA	15	14	14	16	15	15
	40 mm DGA (mid block)	18	17	17	19	18	18
	40 mm DGA (intersections)	32	30	30	34	33	33
	30 mm OGA on 30 mm DGA	44	43	43	46	44	44
1a5	30 mm DGA	16	15	15	17	17	17
	40 mm DGA (mid block)	19	18	18	20	19	19
	40 mm DGA (intersections)	34	32	32	36	35	35
	30 mm OGA on 30 mm DGA	45	43	43	47	45	45
1b, 1c and 1d	30 mm DGA	47	44	44	50	48	48
	40 mm DGA (mid block or intersections)	50	48	48	54	51	51

Pavement type	Surface description	DGA with C170 or C320 bitumen			DGA with polymer modified C170 or C320 bitumen		
		Small-scale $/m²	Medium-scale $/m²	Large-scale $/m²	Small-scale $/m²	Medium-scale $/m²	Large-scale $/m²
	30 mm OGA on 30 mm DGA	74	72	71	77	75	74
2, 3 and 4	40 mm DGA (mid block)	18	17	17	19	18	18
	40 mm DGA (intersections)	31	30	30	34	32	32
	30 mm OGA on 30 mm DGA	46	45	44	48	47	47
5	Plain concrete pavement (PCP)	18	18	18	18	18	18
6	Continuously reinforced concrete pavement (CRCP)	7	7	7	7	7	7
6a	30 mm OGA	32	31	30	32	31	30

Table E 3: Discounted maintenance costs Port Hedland region

Pavement type	Surface description	DGA with C170 or C320 bitumen			DGA with polymer modified C170 or C320 bitumen		
		Small-scale $/m²	Medium-scale $/m²	Large-scale $/m²	Small-scale $/m²	Medium-scale $/m²	Large-scale $/m²
1a	30 mm DGA	42	25	23	43	26	25
	40 mm DGA (mid block)	49	31	29	50	32	31
	40 mm DGA (intersections)	94	57	54	98	61	57
	30 mm OGA on 30 mm DGA	127	78	74	129	81	76
1b, 1c and 1d	30 mm DGA	157	79	71	161	84	75
	40 mm DGA (mid block or intersections)	172	91	82	177	95	87
	30 mm OGA on 30 mm DGA	211	130	122	215	134	126
2, 3 and 4	40 mm DGA (mid block)	49	31	29	50	32	31
	40 mm DGA (intersections)	92	56	53	95	60	56
	30 mm OGA on 30 mm DGA	136	85	80	139	88	83
5	Plain concrete pavement (PCP)	47	41	40	47	41	40
6	Continuously reinforced concrete pavement (CRCP)	17	15	15	17	15	15
6a	30 mm OGA	121	63	57	121	63	57

Table E 4: Discounted maintenance costs Broome region

Pavement type	Surface description	DGA with C170 or C320 bitumen			DGA with polymer modified C170 or C320 bitumen		
		Small-scale $/m²	Medium-scale $/m²	Large-scale $/m²	Small-scale $/m²	Medium-scale $/m²	Large-scale $/m²
1a	30 mm DGA	40	23	21	42	25	23
	40 mm DGA (mid block)	47	29	27	48	30	29
	40 mm DGA (intersections)	90	53	52	93	57	55
	30 mm OGA on 30 mm DGA	122	73	69	124	76	72
1b, 1c and 1d	30 mm DGA	152	74	67	157	79	71
	40 mm DGA (mid block or intersections)	166	84	76	171	89	81
	30 mm OGA on 30 mm DGA	203	122	114	207	126	118
2, 3 and 4	40 mm DGA (mid block)	47	29	27	48	30	29
	40 mm DGA (intersections)	87	52	49	91	56	52
	30 mm OGA on 30 mm DGA	130	79	74	133	82	77
5	Plain concrete pavement (PCP)	47	41	40	47	41	40
6	Continuously reinforced concrete pavement (CRCP)	17	15	15	17	15	15
6a	30 mm OGA	118	60	54	36	60	54

APPENDIX F EXAMPLES OF WOLCC

This appendix contains examples of WOLCC calculated with a discount rate of 7% for the four regions.

F.1 Bunbury Region

F.1.1 Freeways

Figure F 1 and Figure F 2 show examples of the calculated WOLCC for Bunbury freeways based on unit rates for large-scale works. The surfacing comprises open graded asphalt wearing course support by one of the following:

- 30 mm thick size 10 dense graded asphalt with C170 bitumen (P1b, P1c, P1d)
- 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen (P2, P3 and P4) or
- continuously reinforced concrete base (P6a).

For a subgrade design CBR of 3%, the thin asphalt surfaced HCTCRB with granular subbase pavement (P1b) is lowest cost up to its maximum 40 year design traffic loading (about 5 x 10^7 ESA). Thereafter full-depth asphalt pavement (P2) has the lowest cost.

For subgrade design CBR of 12%, full-depth asphalt pavement (P2) generally has the lowest cost.

Note that HCTCRB is yet to be produced in the Bunbury region. Until such time as it is produced full-depth asphalt pavements (P2) generally have the WOLCC.

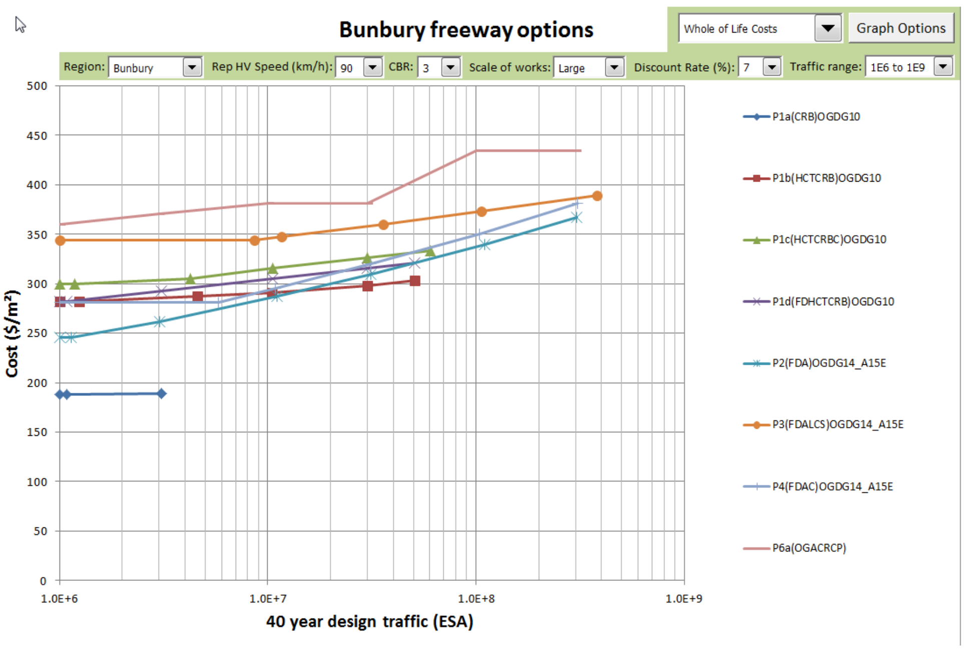

Figure F 1: WOLCC for Bunbury region with open graded asphalt surfacing, subgrade design CBR = 3% and design speed 90 km/h

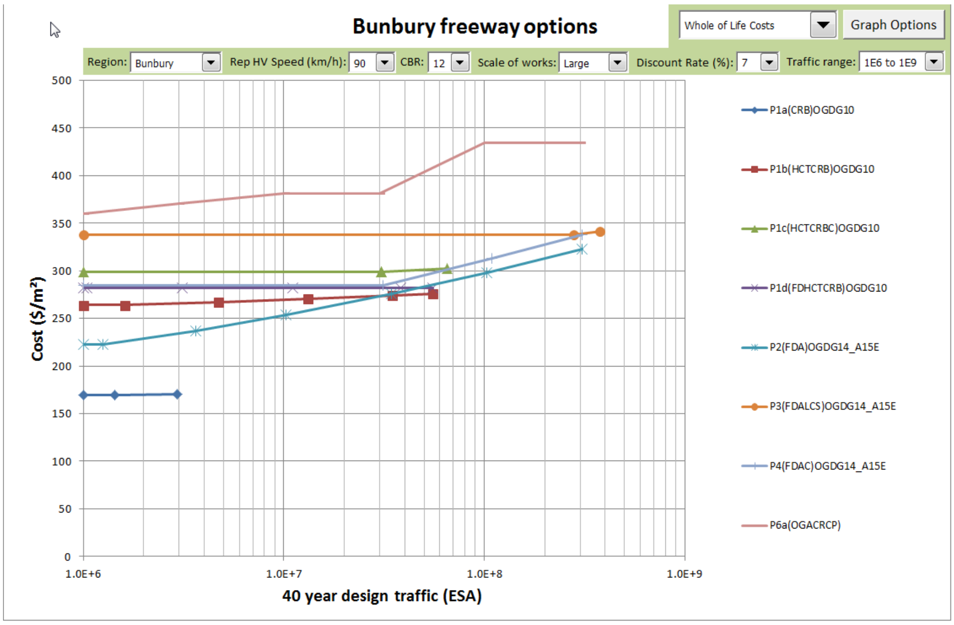

Figure F 2: WOLCC for Bunbury region freeways with open graded asphalt surfacing, subgrade design CBR = 12%, and design speed 90 km/h

F.1.2 Arterial roads

Figure F 3 and Figure F 4 are examples of the calculated WOLCC for Bunbury arterial roads based on unit rates for medium-scale works. Except for the concrete pavement options, the wearing course is either:

- 30 mm thick size 10 dense graded asphalt with C170 bitumen (P1a, P1b, P1c, P1d) or
- 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen (P2, P3 and P4).

Figure F 3 and Figure F 4 indicate that asphalt on crushed rock base (P1a) has the lowest initial cost for Bunbury arterial roads. However, for 40 year design traffic loading exceeding about 4 x 10^6 ESA this pavement type has insufficient asphalt fatigue. In such cases, the full-depth asphalt (P2) generally has the lowest in cost. However if there are arterial roads with 40 year design traffic exceeding about 3 x 10^7 ESA, the thin asphalt surfaced HCTCRB pavement (P1b) has the lowest WOLCC. Note, however, that HCTCRB is yet to be produced in the Bunbury region.

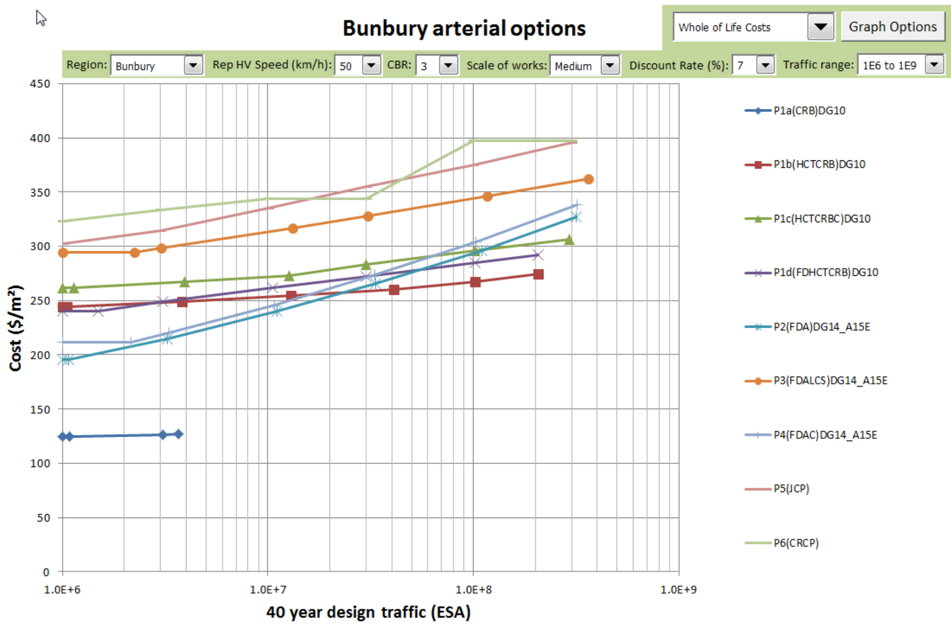

Figure F 3: WOLCC for Bunbury region arterial roads with dense graded asphalt surfacing, subgrade design CBR = 3% and design speed 50 km/h

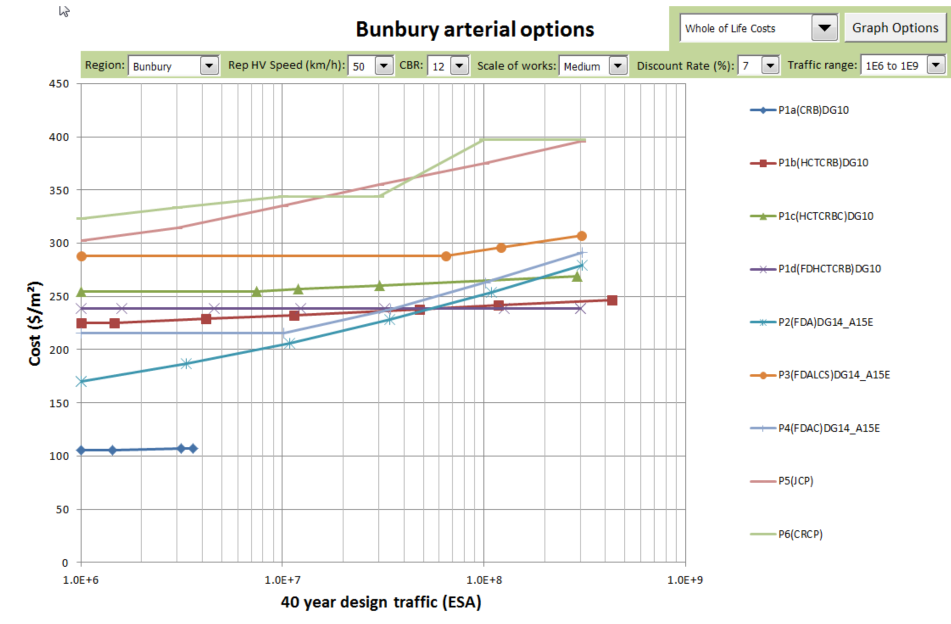

Figure F 4: WOLCC for Bunbury region arterial roads with dense graded asphalt surfacing, subgrade design CBR = 12%, design speed 50 km/h and unit rates based on medium-scale works

F.1.3 Signalised intersections

Figure D 5 and Figure D 6 are examples of the calculated initial construction costs for Bunbury intersections based on unit rates for small-scale works. Except for the concrete pavement options, the wearing course is 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen.

Figure D 5 and Figure D 6 indicate full-depth asphalt pavements (P2) or deep strength asphalt pavements (P4) are the lowest costs, as thin asphalt crushed rock base pavements (P1a) have inadequate asphalt fatigue life.

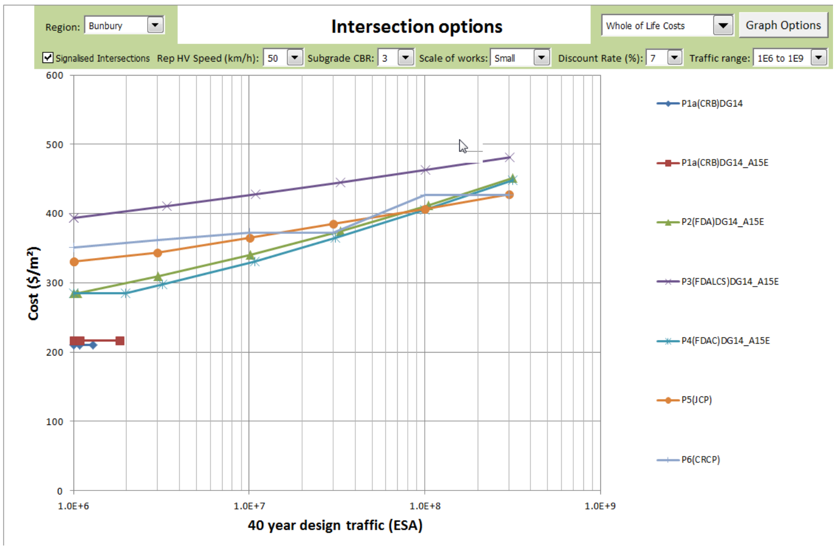

Figure F 5: WOLCC for Bunbury region signalised intersections with dense graded asphalt surfacing, subgrade design CBR = 3%

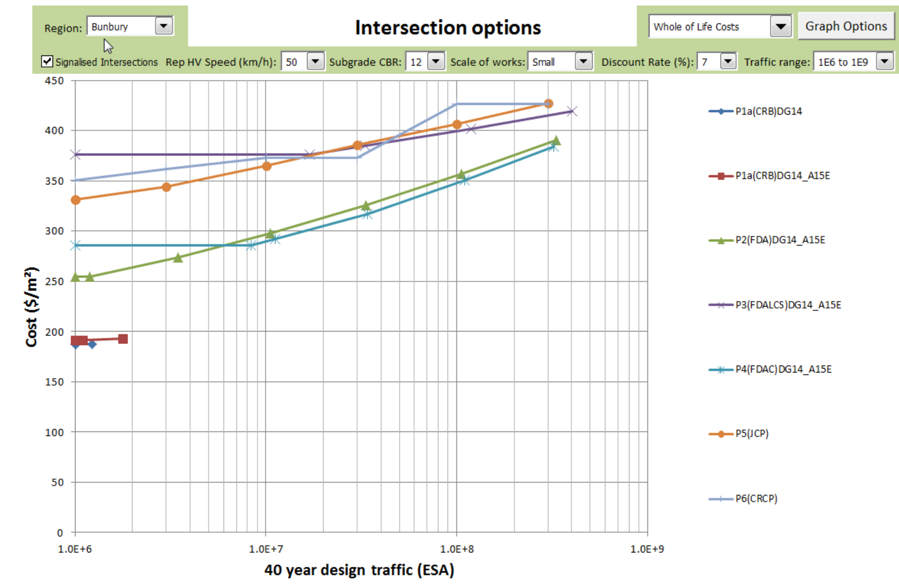

Figure F 6: WOLCC for Bunbury region signalised intersections with dense graded asphalt surfacing, subgrade design CBR = 12%

F.2 Perth Region

F.2.1 Freeways

Figure F 7 and Figure F 8 are examples of the calculated WOLCC for Perth freeways based on unit rates for large-scale works. The surfacing comprises an open graded asphalt wearing course with one of the following:

- 30 mm thick size 10 dense graded asphalt with C170 bitumen (P1a5, P1b, P1c, P1d)
- 40 mm thick size 14 dense graded asphalt with an A15E polymer modified C320 bitumen (P2, P3 and P4) or
- continuously reinforced concrete base (P6a).

As expected for the more lightly-loaded freeways (< 8 x 10^7 ESA), thin asphalt surfaced HCTCRB pavements are clearly the lowest in cost. For the common case of a subgrade design CBR of 12%, Figure F 8 indicates that HCTCRB on crushed limestone subbase (P1b) and full-depth HCTCRB (P1d) have similar costs and maximum design traffic loadings.

For freeways where the 40 year design traffic loading exceeds the maximum allowable loading (about 8 x10^7 ESA) of thin asphalt surfaced HCTCRB pavements, the full-depth asphalt pavements (P2) or deep strength asphalt pavements (P4) are the lowest options.

The CRCP concrete pavement with open graded asphalt surface (P6a) clearly has the highest cost.

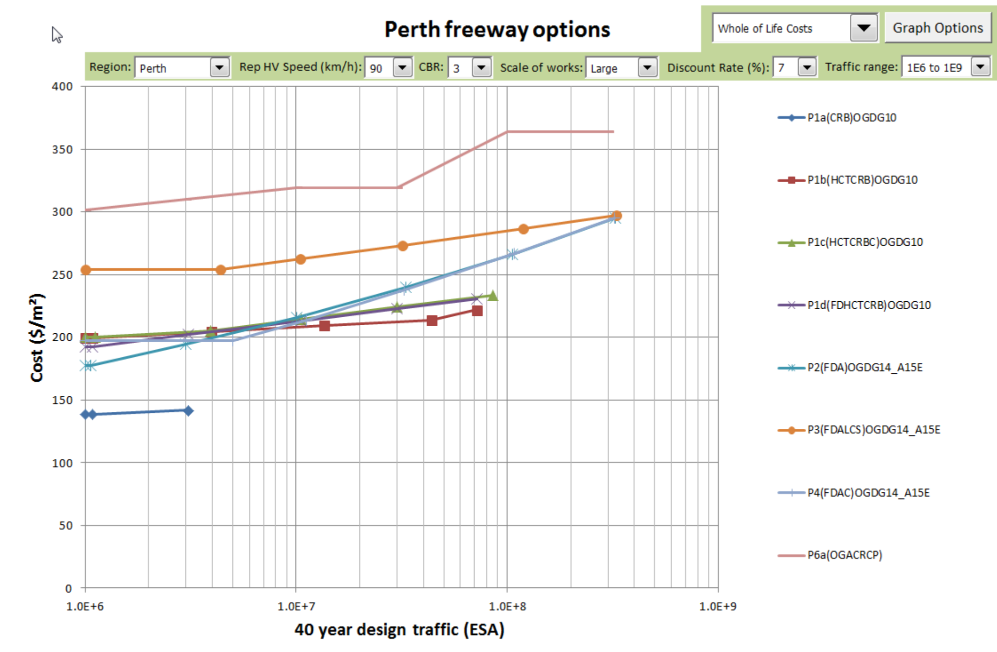

Figure F 7: WOLCC for Perth freeways with open graded asphalt surfacing, subgrade design CBR = 3% and design speed 90 km/h

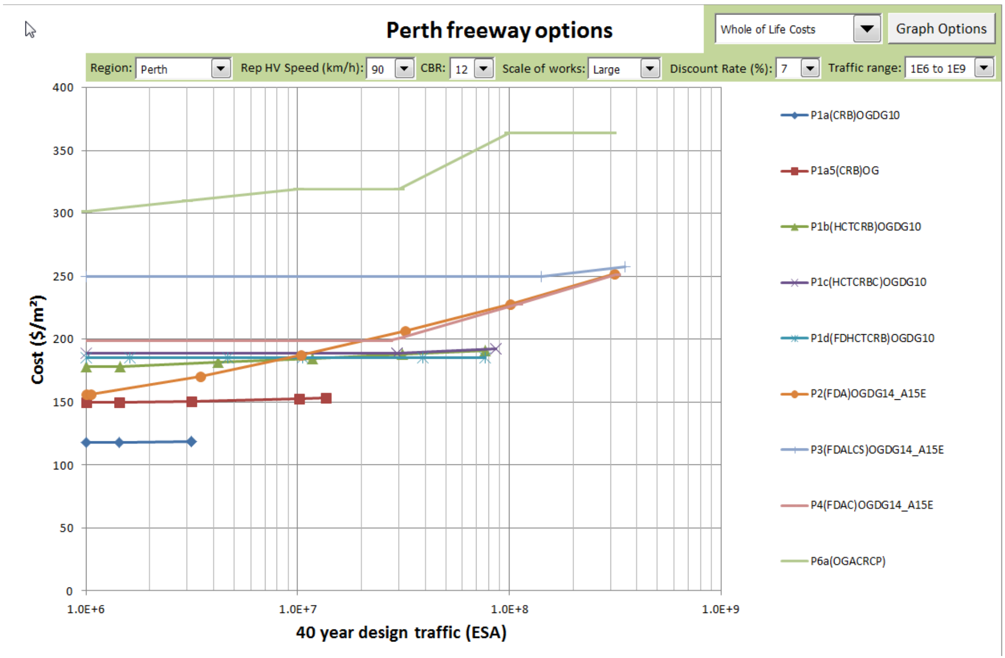

Figure F 8: WOLCC for Perth freeways with open graded asphalt surfacings, subgrade design CBR = 12% and design speed 90 km/h

F.2.2 Arterial Roads

Figure F 9 and Figure F 10 illustrate examples of the WOLCC for Perth arterial roads based on unit rates for medium-scale works. Except for the concrete pavement options, the wearing course was either:

- 30 mm thick size 10 dense graded asphalt using C170 bitumen (P1a, P1a5, P1b. P1c, P1d) or
- 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen (P2, P3 and P4).

As part of the project, Main Roads WA requested evaluation of Pavement Type 1a5, thin asphalt surfaced crushed rock base pavements designed with a 5 year asphalt fatigue life rather than the current practice of specifying a 15 year fatigue life. This design criteria is only for Perth pavements on sand subgrades (CBR = 12).

Figure F 9 and Figure F 10 indicate that asphalt on crushed rock base (Types P1a and P1a5) have the lowest construction cost for Perth arterial roads. For commonly used subgrade design CBR of 12% (sand), the maximum allowable traffic loading over 40 years of thin asphalt surface granular pavements with 5 year fatigue life (P1a5) is about 3 x 10^7 ESA. For very heavily trafficked arterials, thin asphalt on full-depth HCTCRB pavements (P1d) have the lowest cost.

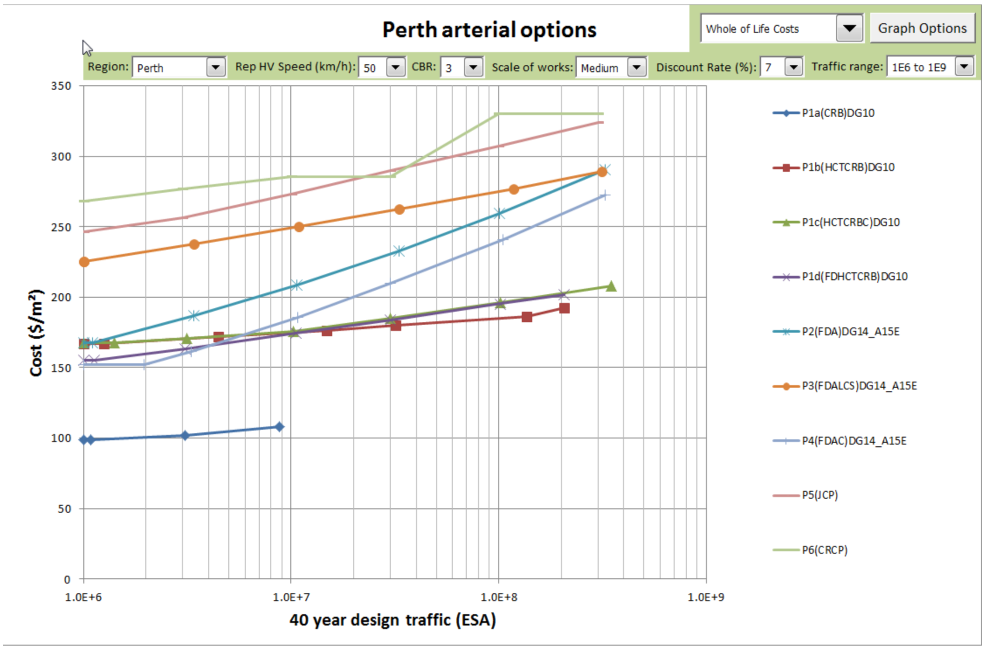

Figure F 9: WOLCC for Perth region urban arterials with dense graded asphalt surfacing, subgrade design CBR = 3% and design speed 50 km/h

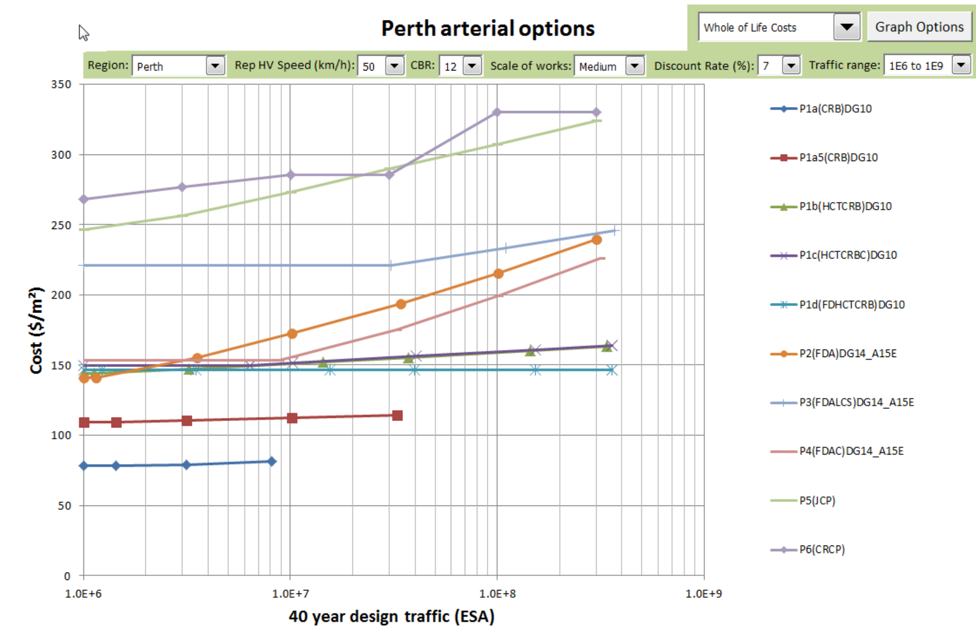

Figure F 10: WOLCC Perth region urban arterials with dense graded asphalt surfacing, subgrade design CBR = 12% and design speed 50 km/h

F.2.3 Signalised Intersections

Figure F 11 and Figure F 12 are examples of the calculated WOLCC for Perth signalised intersections based on unit rates for small-scale works. Except for the concrete pavement options, the wearing course is 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen.

Figure F 11 and Figure F 12 indicate that thin asphalt surfaced crushed rock base pavements (P1a and P1a5) have the lowest construction costs. For commonly used subgrade design CBR of 12% (sand), the maximum allowable traffic loading over 40 years of thin asphalt surface granular pavements with 5 year fatigue life (P1a5) is about 8 x 10^6 ESA (note that ERN9 does not allow increase in life due to use of polymer modified binder). Note that although Main Roads WA ENRN 9 requires the use of polymer modified binder A15E at intersections for rut-resistance, no allowance is made for the calculated increase in fatigue life due its lower modulus. For 40 year traffic loading greater than 8 x 10^6 ESA, thick asphalt on cement treated crushed rock subbase pavements (P4) are the lowest cost.

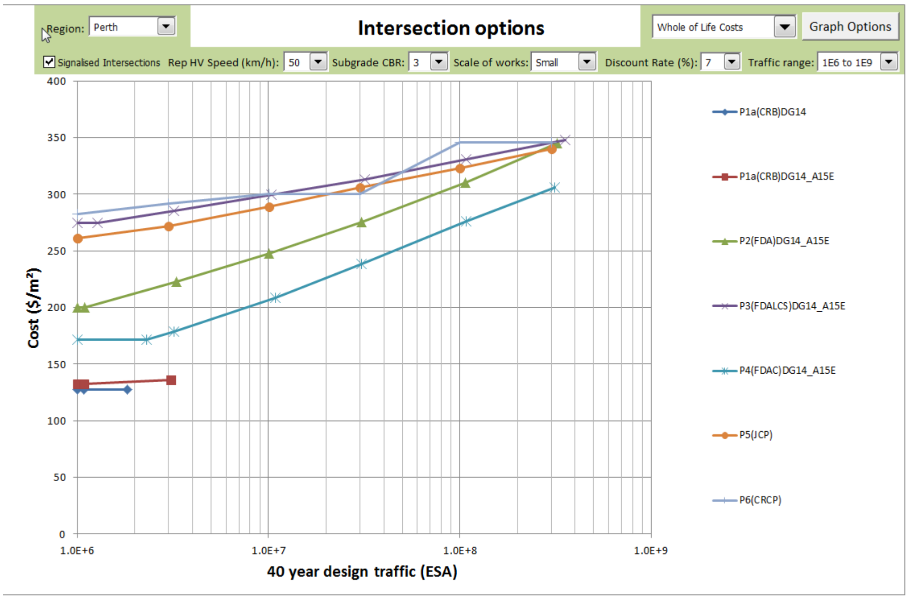

Figure F 11: WOLCC for Perth region signalised intersections, subgrade design CBR = 3%

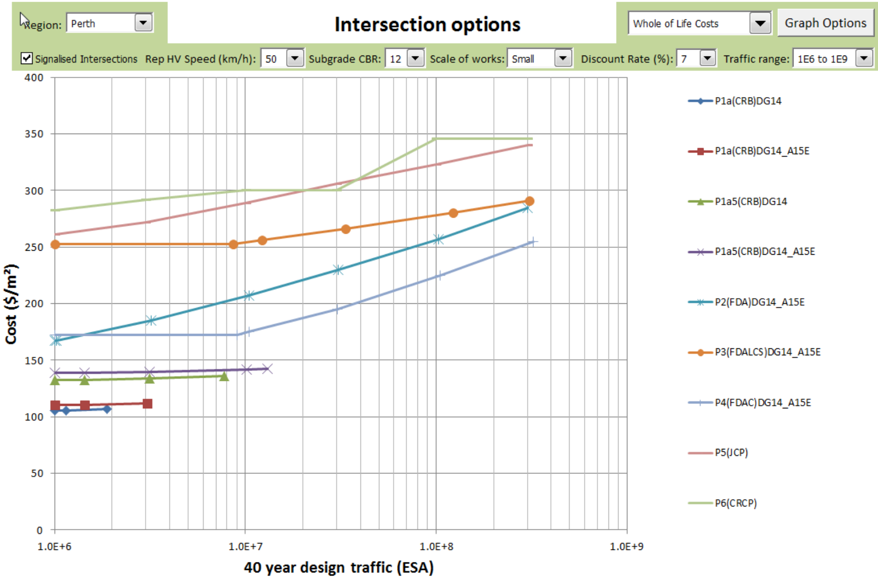

Figure F 12: WOLCC for Perth region signalised intersections, subgrade design CBR = 12%

F.3 Port Hedland Region

F.3.1 Freeways

Figure F 13 and Figure F 14 are examples of the calculated WOLCC for Port Hedland freeways based on unit rates for large-scale works. The surfacing comprises an open graded asphalt wearing course with one of the following:

- 30 mm thick size 10 dense graded asphalt with C170 bitumen (P1a, P1b. P1c, P1d)
- 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen (P2, P3 and P4) or
- continuously reinforced concrete base (P6a).

As expected, thin asphalt surfaced HCTCRB pavements (P1b, P1d) have clearly the lowest WOLCC.

Note that HCTCRB is yet to be produced in the Port Hedland region. Until such time as it is produced, deep strength asphalt pavements (P4) have the lowest cost.

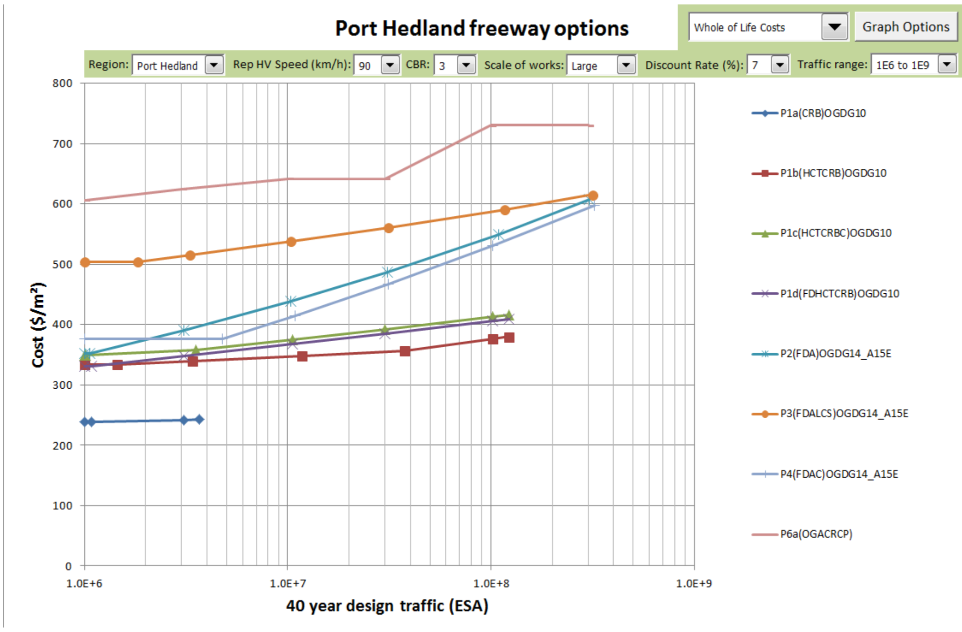

Figure F 13: WOLCC for Port Hedland region freeways with open graded asphalt surfacing, subgrade design CBR = 3% and design speed 90 km/h

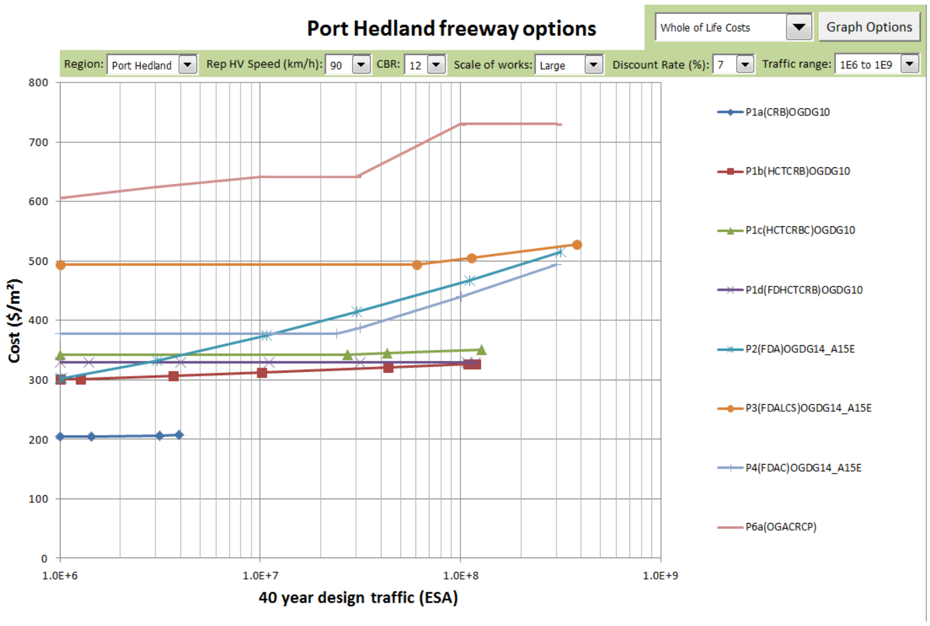

Figure F 14: WOLCC for Port Hedland region freeways with open graded asphalt surfacing: subgrade design CBR = 12% and design speed 90 km/h

F.3.2 Arterial Roads

Figure F 15 and Figure F 16 are examples of the calculated WOLCC for Port Hedland arterial roads based on unit rates for medium-scale works. Except for the concrete pavement options, the wearing course is either:

- 30 mm thick size 10 dense graded asphalt with C170 bitumen (P1a, P1b, P1c, P1d) or
- 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen (P2, P3 and P4).

Figure F 15 and Figure F 16 indicate that thin asphalt surfaced crushed rock base pavements (P1a) have the lowest WOLCC for Port Hedland arterial roads up to a 40 year design traffic loading of about 3 x 10^7 ESA. At higher traffic loadings, thin asphalt surfaced HCTCRB pavements (P1b, P1d) are clearly the lowest in cost.

Note that HCTCRB is yet to be produced in the Port Hedland region. Until such time as it is produced, deep strength asphalt pavements (P4) have the lowest WOLCC.

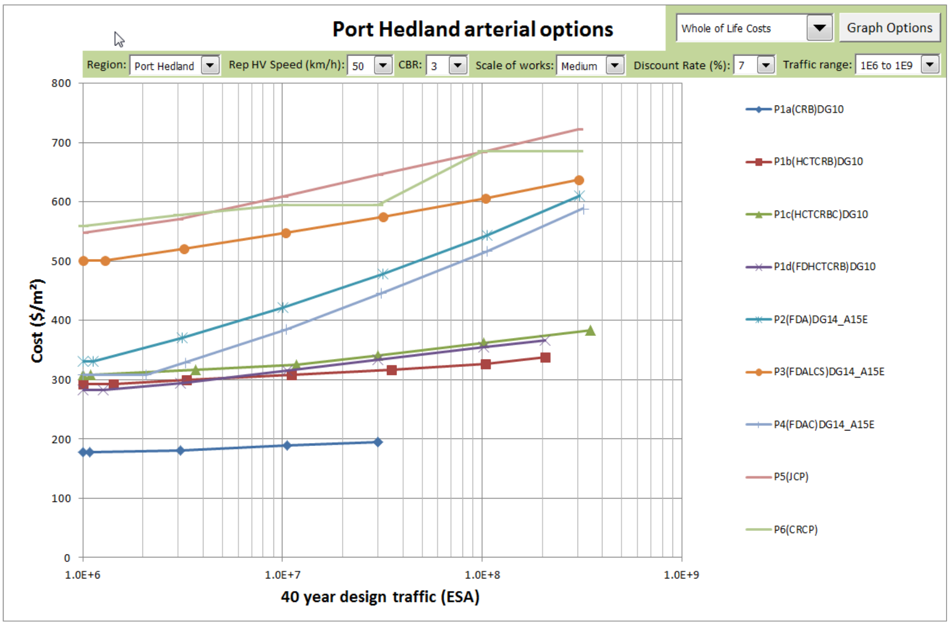

Figure F 15: WOLCC for Port Hedland region arterial roads with dense graded asphalt surfacing, subgrade design CBR = 3% and design speed 50 km/h

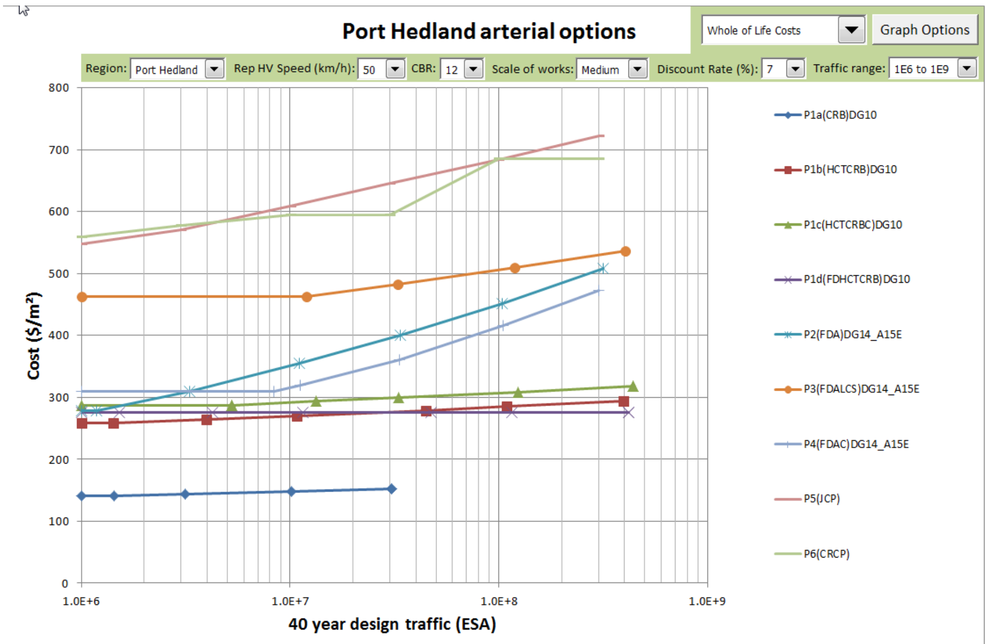

Figure F 16: WOLCC for Port Hedland region arterial roads with dense graded asphalt surfacing, subgrade design CBR = 12% and design speed 50 km/h

F.3.3 Signalised Intersections

Figure F 17 and Figure F 18 are examples of the calculated WOLCC for Port Hedland signalised intersections based on unit rates for small-scale works. Except for the concrete pavement options, the wearing course is 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen.

Figure F 17 and Figure F 18 indicate that thin asphalt surfaced crushed rock base pavements (P1a) have the lowest WOLCC for Port Hedland signalised intersections. However, the maximum allowable loading of the 40 mm thick asphalt surfacing is low, about 10^7 ESA. In the event the 40 year design traffic loading exceeds the capability of thin asphalt surfaced crushed rock base pavements, deep strength asphalt pavements (P4) have the lowest WOLCC.

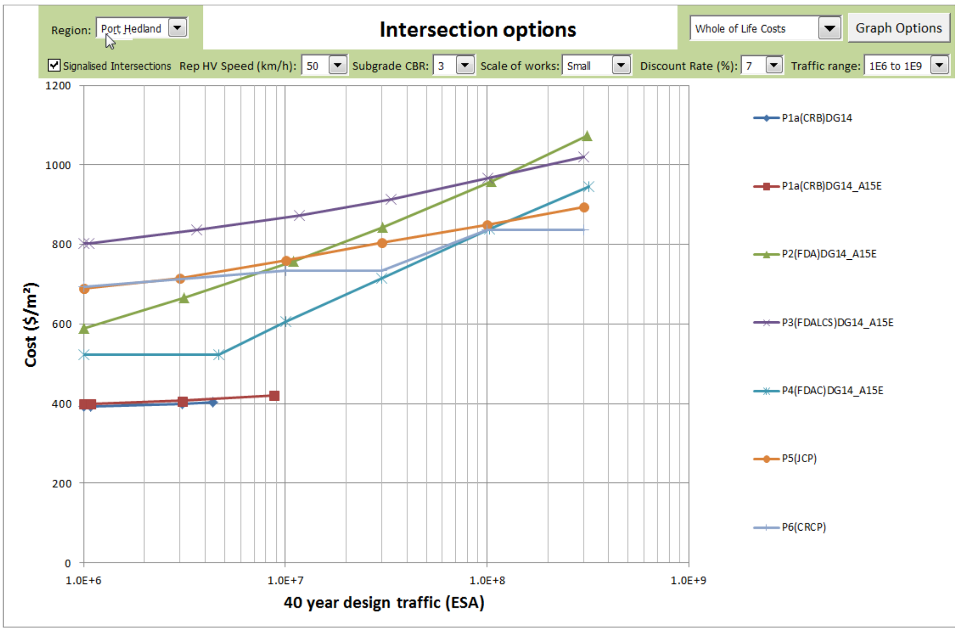

Figure F 17: WOLCC for Port Hedland region signalised intersections with dense graded asphalt surfacing, subgrade design CBR = 3%

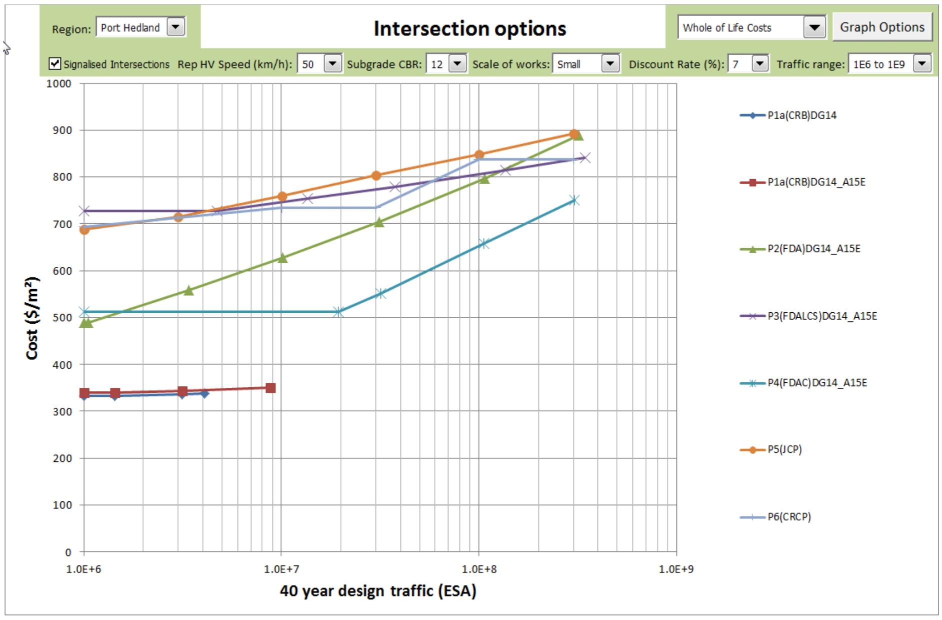

Figure F 18: **WOLCC for Port Hedland region signalised intersections with dense graded asphalt surfacing, subgrade design CBR = 12%**

F.4 Broome Region

F.4.1 Freeways

Figure F 19 and Figure F 20 are examples of the calculated WOLCC for Broome freeways based on unit rates for large-scale works. The surfacing comprises an open graded asphalt wearing course supported by one of the following:

- 30 mm thick size 10 dense graded asphalt with C170 bitumen (P1a, P1b, P1c, P1d)
- 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen (P2, P3 and P4) or
- continuously reinforced concrete base (P6a).

As expected thin asphalt surfaced HCTCRB pavements (P1b and P1d) have the lowest WOLCC.

Note that HCTCRB is yet to be produced in the Broome region. Until such time as it is produced deep strength asphalt pavements (P4) will have the lowest cost.

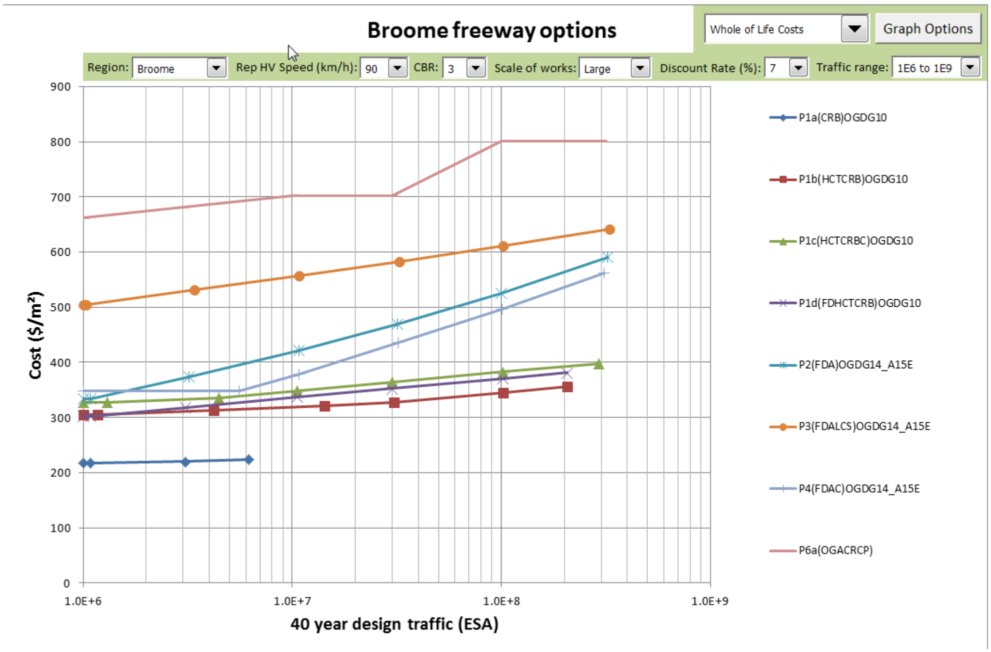

Figure F 19: WOLCC for Broome region freeways with open graded asphalt surfacing, subgrade design CBR = 3% and design speed 90 km/h

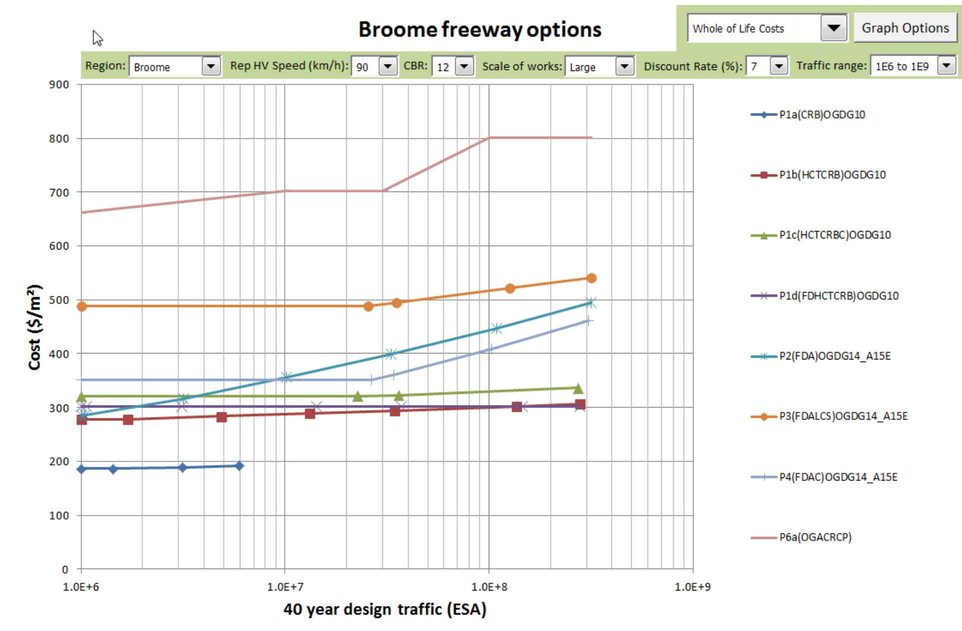

Figure F 20: WOLCC for Broome region freeways with open graded asphalt surfacing, subgrade design CBR = 12% and design speed 90 km/h

F.4.2 Arterial roads

Figure F 21 and Figure F 22 are examples of the calculated WOLCC for Broome arterial roads based on unit rates for medium-scale works. Except for the concrete pavement options, the wearing course is either:

- 30 mm thick size 10 dense graded asphalt with C170 bitumen (P1a, P1b, P1c, P1d) or

- 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen (P2, P3 and P4).

Figure F 21 and Figure F 22 indicate that thin asphalt surfaced crushed rock base pavements (P1a) have the lowest WOLCC for Broome arterial roads.

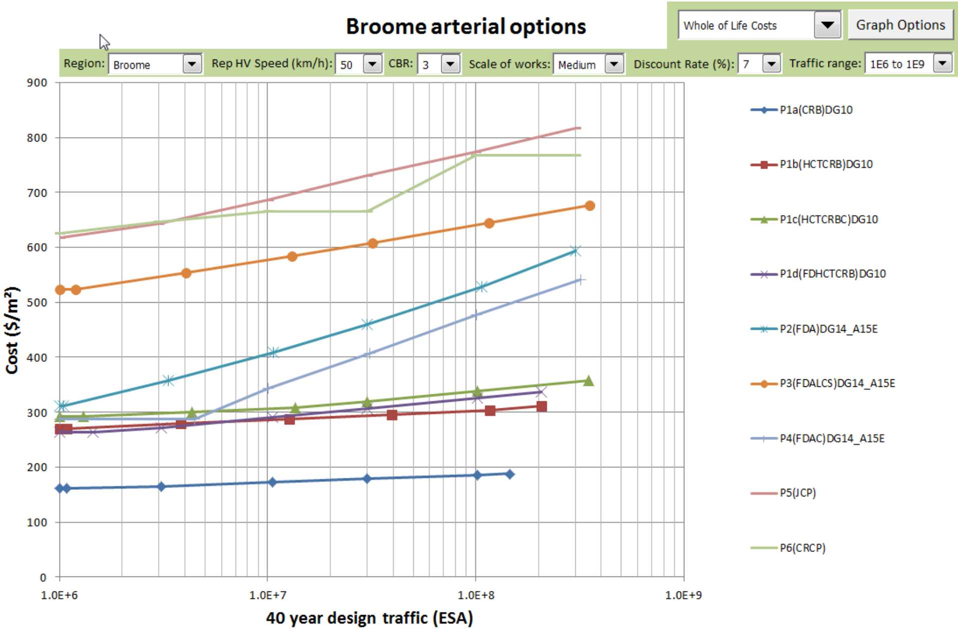

Figure F 21: WOLCC for Broome region arterial roads with dense graded asphalt surfacing, subgrade design CBR = 3% and design speed 50 km/h

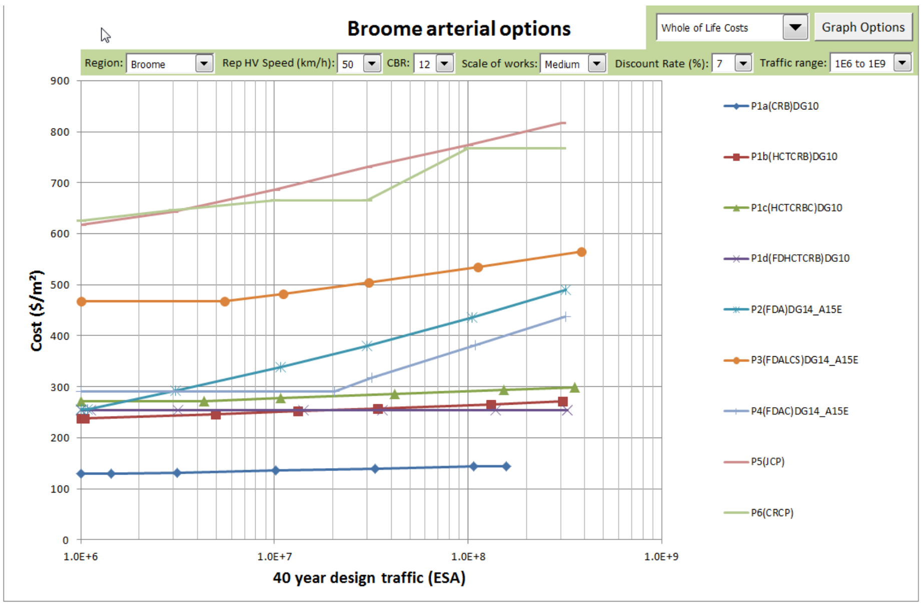

Figure F 22: WOLCC for Broome region arterial roads with dense graded asphalt surfacing, subgrade design CBR = 12% and design speed 50 km/h

F.4.3 Signalised intersections

Figure F 23 and Figure F 24 are examples of the calculated WOLCC for Broome signalised intersections based on unit rates for small-scale works. Except for the concrete pavement options, the wearing course is 40 mm thick size 14 dense graded asphalt using A15E polymer modified C320 bitumen.

The cost rankings are similar to those for Broome arterials. Figure F 23 and Figure F 24 indicate that thin asphalt surfaced crushed rock base pavements (P1a) have the lowest WOLCC for Broome signalised intersections.

However, the maximum allowable loading of the 40 mm thick asphalt surfacing is low, about 2×10^7 ESA. In the event the 40 year design traffic loading exceeds the capability of thin asphalt, surfaced crushed rock base pavements, deep strength asphalt pavements (P4) have the lowest WOLCC.

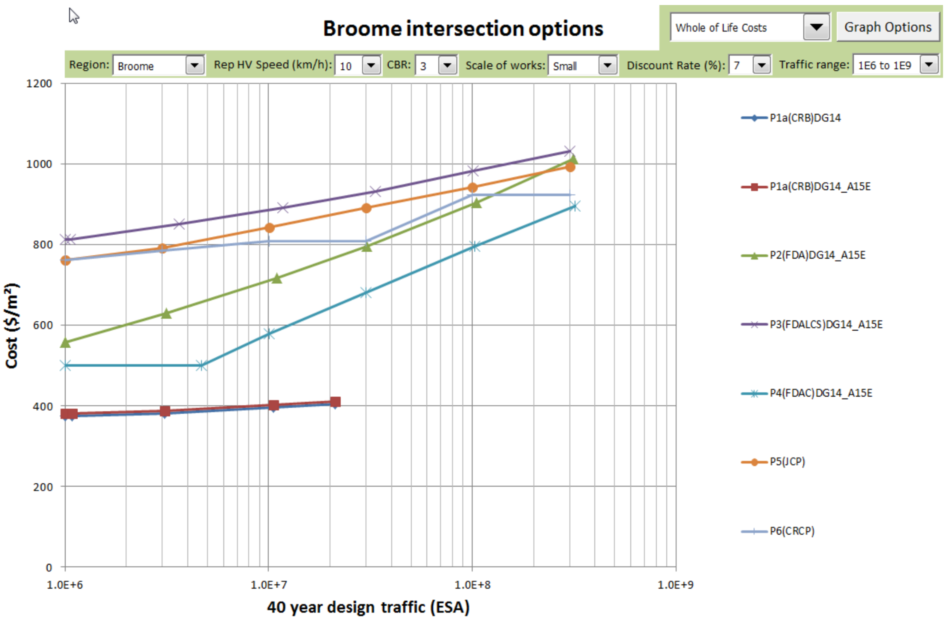

Figure F 23: WOLCC for Broome region signalised intersections with dense graded asphalt surfacing, subgrade design CBR = 3%

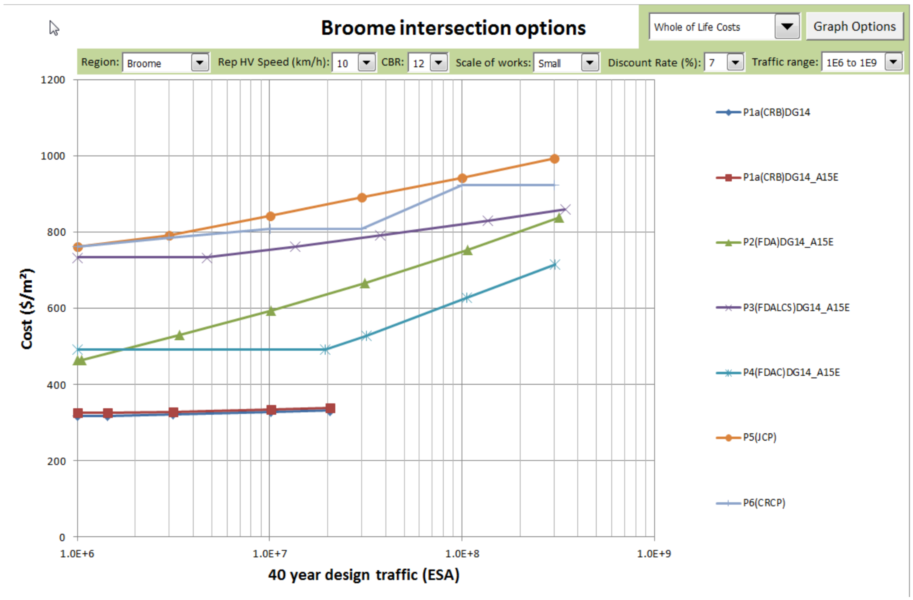

Figure F 24: WOLCC for Broome region signalised intersections with dense graded asphalt surfacing, subgrade design CBR = 12%