



TR  
st(VT) = Delay(VT)  
Total TTC  
TVEHR(VT) CrashCost  
= MVK<sup>60</sup> A  
= MVK<sup>60</sup> A  
140  
Total TTC  
AADT(VT)  
x (Trip Time(VT))

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## Technical guide



# 4

## 1 Introduction to the technical guide

The *Technical Guide* provides detailed information and explanations on calculations underlying CBA6. This document is a useful resource for anyone involved in testing and comparing project evaluation models, for example, researchers, consultants, economists, engineers and software developers.

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## 1.1 Introduction

The purpose of the *Technical Guide* is to provide a complete breakdown of all algorithms, formulae and parameters in CBA6. This includes important outputs such as operating speed, VOC, TTC, accident costs and the decision criteria.

CBA6 pricing, common structures and unit values are created, maintained and updated periodically and internally by TMR and as such cannot be modified by the system user. To maintain the integrity of the tool, CBA6 pricing, common structures and unit values are derived from external sources such as Austroads and ATC guidelines.

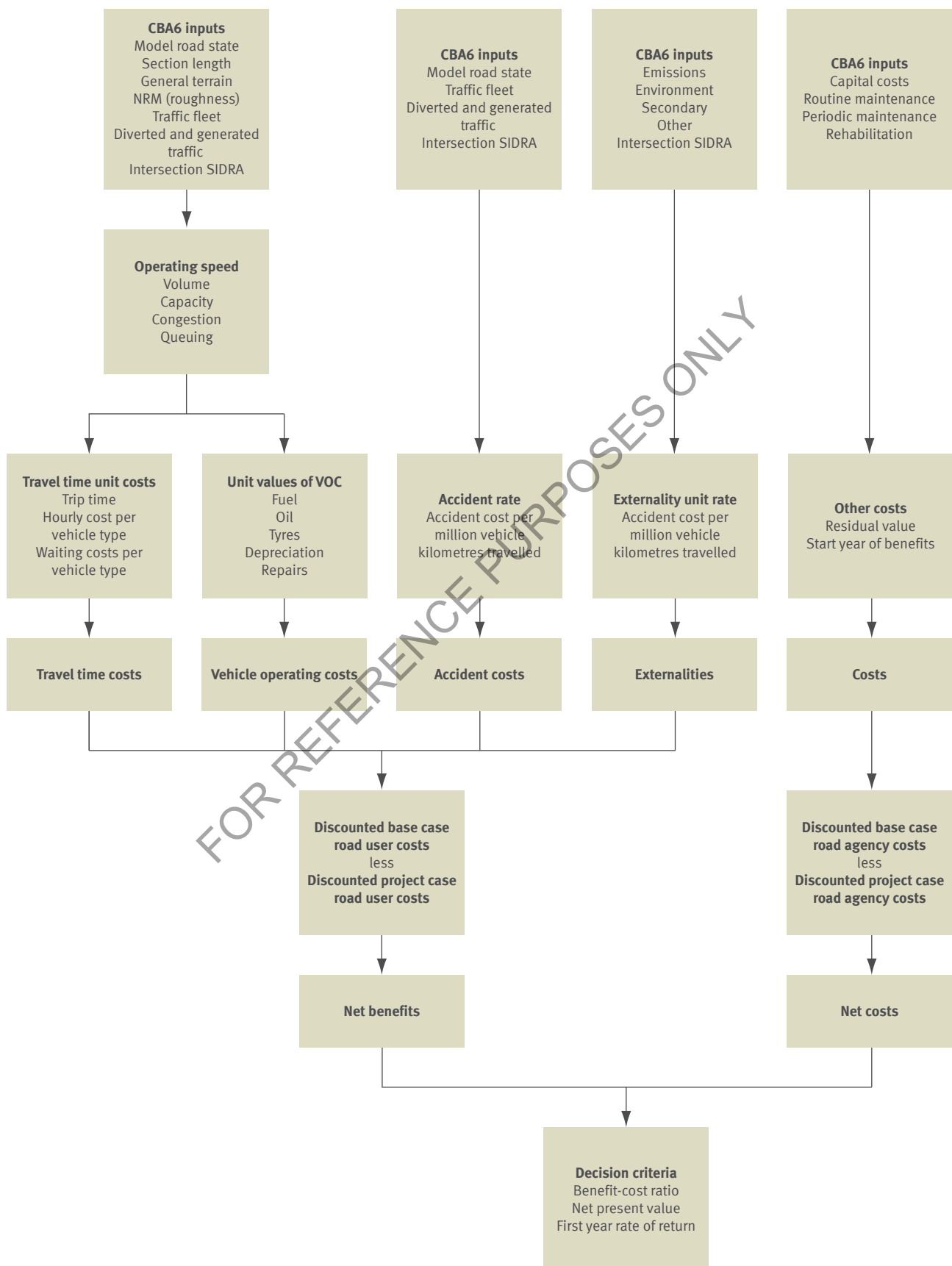
The *Technical Guide* also provides the relevant algorithms and methodology for advanced modules available in CBA6, including:

- road closures with a diverting route
- road closures with no diverting route
- generated traffic
- bypass
- overtaking lanes
- livestock damage
- intersections.

The process structure of CBA6 is illustrated by Figure 1. This figure highlights the relationships between inputs entered by system users and CBA6 calculations and outputs. The *Technical Guide* discusses these relationships in further detail and shows how inputs influence outputs, which can then be used to demonstrate the overall economic justification for a project.

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Figure 1: CBA6 structural processes



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## 1.2 Harmonisation summary

CBA6 has been developed consistent with, and based on, NAASRA Improved Model for Project Assessment and Costing (NIMPAC) standards as documented in the Austroads harmonisation paper AP-R264/05, to derive road user costs. AP-R264/05 was created in conjunction with research undertaken by the Austroads Road User Effects Reference Group (RUERG). RUERG was comprised of technical representatives and evaluation system users from all state jurisdictions and the private sector, and had the intention of testing and harmonising the calculations in NIMPAC evaluation models with the international highway demand management (HDM) model. AP-R264/05 consequently compared state models to the international HDM model.

RUERG established and revised NIMPAC algorithms for adoption in each state which derived comparable results to the HDM model. Each jurisdiction, subsequently, incorporated the changes into their respective project evaluation models to ensure the consistency and transparency of the results. The harmonisation process continued in 2006 with the federal government and ARRB investigating a process to consider using the updated HDM-4 as a tool to conduct all road project evaluation work across the national highway network.

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## 1.3 Outline of the *Technical Guide*

The layout of the *Technical Guide* is set out in the same order as the calculations within CBA6, which is shown by Figure 1.

**2 Volume capacity ratio** sets out the formulae used by CBA6 to calculate the level of congestion based on traffic inputs and road characteristics. The VCR incorporates traffic volume and growth rates and the road capacity based on peak hour usage. CBA6 calculates the operating speed of the fleet based on the VCR.

**3 Operating speed** shows the formulae and assumptions made in this calculation. Operating speed is one of the most important calculations made in CBA6, as it has a direct effect on the value of VOC and TTC.

**4 Vehicle operating costs** sets out the formulae and unit values used to calculate VOC. These costs are made up of fuel, oil, tyre, repairs and maintenance, depreciation and interest costs. These costs vary according to operating speed, road roughness and road alignment.

**5 Travel time costs** shows the TTC incurred by motorists according to journey time and the economic value of time.

**6 Accident costs** contains the average accident cost for Queensland and the accident rate for each road stereotype, and discusses accident and crash costs.

**7 Externalities** presents information on the calculation of externalities. This includes calculations for air pollution, greenhouse gas, noise, water, nature and landscape, urban separation and upstream and downstream costs.

**8 Advanced projects** applies these calculations to the advanced project modules used in CBA6 including road closures, intersections, overtaking lanes, generated traffic, livestock and bypasses.

**9 Decision criteria** used by CBA6 are mathematically defined. These criteria include BCR, NPV, FYRR, IBCR and NPVI.

**10 Sensitivity testing** explains the formulae applied to the sensitivity testing of the parameters in CBA6.

**11 Effects of intermediate outputs** contains a final summary of the effect inputs have on CBA6 outputs.

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## 2 Volume capacity ratio

This section of the *Technical Guide* outlines the equations used in the derivation of the VCR and the calculations of traffic volume and road capacity. The VCR is an important calculation in CBA6 as it is central to the calculation of operating speed and many of the congestion adjustments in the VOC algorithms.

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## 2.1 Traffic volume

AADT and vertical alignment inputs to CBA6 are used to calculate the volume of traffic on the road using passenger car equivalents (PCE). The AADT value is converted into PCEs to measure traffic volume.

PCE factors for each vehicle type are shown by Table 1 for example, a B-double on a section of road with an entire grade of 4% is equivalent in volume to 8.1 passenger cars.

Table 1: Passenger car equivalent factors

Vehicle type	Flat	Grade 4%	Grade 6%	Grade 8%	Grade 10%
Cars– private	1.0000	1.0000	1.0000	1.0000	1.0000
Cars – commercial	1.0667	1.1667	1.3333	1.6667	2.0000
Non-Articulated	1.4000	2.1000	2.8000	4.2000	5.2222
Buses	1.7000	3.0000	4.0000	6.0000	7.0000
Articulated	2.4000	4.8000	7.2000	9.6000	12.0000
B-double	4.1000	8.1000	12.2000	16.2000	20.3000
Road train 1	4.9500	9.8500	14.8500	19.7500	24.7000
Road train 2	8.8000	17.6000	26.5000	35.3000	44.1000

Source: adapted from Austroads (2005) page 20.

The formula to calculate the traffic volume is shown by Equation 1.

### Equation 1: Traffic volume

$$Volume = \sum_i AADT_i \times PCE_i$$

Where:

- $AADT_i$  = annual average daily traffic count
- $PCE_i$  = passenger car equivalent for vehicle type i

### Example: Traffic volume

On a flat road (100% flat) with AADT of 1000, made up of 616 private cars, 264 commercial cars, 50 rigid vehicles, 10 buses, 50 semis and 10 B-doubles, the corresponding traffic volume is given by:

$$Volume = (616 \times 1) + (264 \times 1.0667) + (50 \times 1.4) + (10 \times 1.7) + (50 \times 2.4) + (10 \times 4.1)$$

$$Volume = 1146$$

Therefore the traffic volume of the road in PCE is 1146. This is notably different from the AADT of 1000.



## 2.2 Traffic growth rate

CBA6 uses the traffic growth rate to calculate the VCR in future years. CBA6 provides two growth options when predicting future traffic volumes, linear growth and compound growth. For further details on the suitability of either growth rate option, see Section 3.5.3.2 of the *User Guide*. The calculation of linear and compound growth rates is given in Section 2.2.1 and Section 2.2.2 respectively.

### 2.2.1 Linear traffic growth

The formula to calculate AADT when the traffic growth rate is linear is given in Equation 2.

*Equation 2: Linear traffic growth*

$$AADT_x = AADT_{y1} + (x - y1) \times \left( (AADT_{y1} \times (1 + GR)) - AADT_{y1} \right)$$

Where:

- $AADT_{y1}$  = AADT in the first year of evaluation
- $AADT_x$  = AADT in year x
- GR = growth rate
- y1 = first year (1)
- x = year of calculation

*Example: Linear traffic growth*

AADT for a given road is 1000 and the linear growth rate is assumed to be 3% p.a. AADT in Year 5 is given by:

$$AADT_5 = 1000 + (5 - 1) \times \left( (1000 \times (1 + 0.03)) - 1000 \right)$$

$$AADT_5 = 1120$$

Note: When using the linear growth forecast, future trends are based solely on the AADT in the year selected for extrapolation.

### 2.2.2 Compound traffic growth

The formula for compound traffic growth is shown by Equation 3.

*Equation 3: Compound traffic growth*

$$AADT_x = AADT_{y1} \times (1 + GR)^{(x-y1)}$$

A compound growth rate is a growth rate which is compounded annually, whereas a linear growth rate results in a constant increase in traffic each year.

*Example: Compound traffic growth*

Using an AADT of 1000, compounded annually at 4% for 5 years, the calculated AADT is given below:

$$AADT_5 = 1000 \times (1 + 0.04)^4$$

$$AADT_5 = 1169.86$$

As demonstrated in this example, AADT can vary substantially depending on the type of growth rate applied. Compound growth in AADT is based on a constant percentage increase in the number of vehicles per year, while linear growth in AADT is based on a constant increase in the actual number of vehicles per year.

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## 2.3 Road capacity

Road capacity is dependent on both the hourly capacity, measured in PCEs, and a peak hour capacity factor by model road state (MRS).

Table 2 lists the hourly capacities in PCE for each MRS. Hourly capacity is dependent on the seal type (undivided or divided) and the seal width.

*Table 2: Hourly PCE capacity*

MRS	Road width description	Hourly capacity (PCE/hr)
1	Unsealed natural surface	400
2	Unsealed formed road	400
3	Paved < 4.5 m	500
4	Paved ≥ 4.5 m	700
5	Narrow seal ≤ 4.5 m	1 500
6	Narrow seal 4.6 m–5.2 m	2 000
7	2 lane seal 5.3 m–5.8 m	2 300
8	2 lane seal 5.9 m–6.4 m	2 350
9	2 lane seal 6.5 m–7.0 m	2 450
10	2 lane seal 7.1 m–7.6 m	2 500
11	2 lane plus shoulder seal 7.7 m–8.2 m	2 525
12	2 lane plus shoulder seal 8.3 m–9.0 m	2 550
13	2 lane plus shoulder seal 9.1 m–9.4 m	2 550
14	2 lane plus shoulder seal 9.5 m–10 m	2 565
15	2 lane plus shoulder seal 10.1 m–11.6 m	2 575
16	3 lane for overtaking	4 000
17	4 lane undivided sealed	7 120
18	6 lane undivided sealed	12 000
19	4 lane divided sealed	8 000
20	6 lane divided sealed	12 000
21	4 lane divided (limited access)	8 000
22	6 lane divided (limited access)	12 000
23	8 lane divided (limited access)	16 000

Source: adapted from Austroads (2005) page 22.

Note: MRS is derived from the Western Australia MRS classification: Austroads (AP-R264/05).

Default peak hour capacity percentages are shown by Table 3. These default figures are used to assess the percentage of AADT that travel during peak periods.

Table 3: Road type and peak hour capacity factor

Road type	Capacity factor
National highway	10
Urban single carriageway	10
Urban dual carriageway	12.5
Rural single carriageway	8.33
Rural dual carriageway	10

Source: TMR.

TMR assumes that 10% of AADT on a national highway travels during peak periods. Similarly, 12.5% of daily traffic travels in peak periods on urban dual carriageways.

Equation 4 is used to calculate the capacity for a given road.

*Equation 4: Road capacity*

$$\text{Capacity} = \frac{\text{Hourly Capacity}}{\text{Capacity Factor \%}}$$

Where:

- Hourly Capacity = hourly capacity in PCE/hr by MRS
- Capacity Factor% = proportion of daily traffic in the peak periods

The hourly capacity rate is set by the corresponding MRS and is a function of the seal width. In CBA6, roads with larger seal widths are assumed to accommodate more vehicles per hour.

*Example: Road capacity*

A national highway with a model road state of 10 would have an hourly capacity of 2500, see Table 2, and a peak hour capacity factor of 10%, see Table 3. In this example, the road capacity is given below:

$$\text{Capacity} = \frac{2500}{10\%}$$

$$\text{Capacity} = 25,000$$

Note: Peak period (1 hour) is determined in CBA6 based on the system user's selection of road description and MRS. The capacity factor is thus used to determine the capacity of the road which in turn influences the VCR. This form of modelling is known as free flow.

## 2.4 Volume capacity ratio

VCR is calculated using the volume calculations shown by Section 2.1 and the capacity calculations shown by Section 2.3.

*Equation 5: Volume capacity ratio*

$$VCR = \frac{\text{Volume}}{\text{Capacity}}$$

Where:

- For further information on VCR, see Section 2.1

The VCR is a measure of the level of congestion on a road given the traffic volume and road capacity. When the VCR reaches 1, this indicates that the road is operating at 100% capacity.

Note: The maximum VCR in CBA6 is 1.25.

*Example: Volume capacity ratio*

Using the examples provided in Sections 2.1 and 2.3, the corresponding VCR is:

$$VCR = \frac{1145}{25,000}$$

$$VCR = 0.046$$

This example illustrates that the current road volume is approximately 4.6% of total road capacity.

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## 3 Operating speed

Operating speed is one of the most important components used in the road user cost calculations of CBA6. Operating speed influences both the VOC and TTC of the base and project cases.

Operating speed is the estimated average speed for each vehicle type on a particular road once adjustments are made for congestion and other road characteristics. Operating speed differs substantially from the posted speed, which is defined as the maximum 'sign posted' speed that vehicles may travel legally.

Operating speed calculation is a function of the following:

- free speed – 3.1
- roughness adjustment – 3.2
- congestion adjustment – 3.3

### 3.1 Free speed

Free speed is the average speed of a vehicle not subject to roughness, congestion or sign posted speed constraints. Free speed is related to the vehicle type, MRS and vertical and horizontal alignment as per Table 4.

A roughness correction is applied to free speed when the road roughness count is greater than 60 NRM. Finally, free speed is adjusted for congestion, according to the VCR, to give the operating speed for each vehicle type.

Table 4: Free speed array

Vehicle type	Road type	Straight grad 0-2%	Straight grad 4%	Straight grad 6%	Straight grad 8%	Straight grad 10%	Curvy grad 0-2%	Curvy grad 4%	Curvy grad 6%	Curvy grad 8%	Curvy grad 10%	V/curvy grad 0-2%	V/curvy grad 4%	V/curvy grad 6%	V/curvy grad 8%	V/curvy grad 10%
Cars – private	≤ 4.5 m	83	82	76	66	56	77	76	72	64	55	69	68	66	60	53
Cars – commercial	≤ 4.5 m	82	79.3	72	61.7	52	75	73	68	59.7	51	67	65.3	62.3	56.3	49.3
Non-Articulated	≤ 4.5 m	82.4	68.8	55.6	44.6	36	73	63.4	53.2	43.4	35.8	64.2	57.6	49.8	42.2	35.6
Buses	≤ 4.5 m	86	72	57	45	37	77	67	55	45	37	67	61	53	44	36
Articulated	≤ 4.5 m	86	49	39	32	24	71	45	38	32	24	59	41	36	31	24
B-double	≤ 4.5 m	88	38	27	20	16	72	35	27	19	16	59	32	26	19	16
Road train 1	≤ 4.5 m	88	38	27	20	16	72	35	27	19	16	59	32	26	19	16
Road train 2	≤ 4.5 m	88	38	27	20	16	72	35	27	19	16	59	32	26	19	16
Cars – private	> 4.5 m	105	102	88	72	59	90	89	81	68	57	75	74	71	63	55
Cars – commercial	> 4.5 m	99.7	95	81.3	66.3	54.3	85.7	83.3	75	63	52.7	72	70.3	66.3	58.7	51
Non-Articulated	> 4.5 m	93.8	74.2	58	45.4	36.2	79.8	67.2	55	44.2	36	67.2	60.2	51.4	42.8	35.8
Buses	> 4.5 m	100	78	59	46	37	85	71	57	45	37	70	63	54	44	36
Articulated	> 4.5 m	100	52	40	32	24	75	47	39	32	24	60	42	36	31	24
B-double	> 4.5 m	100	40	28	20	16	75	36	27	19	16	60	33	26	19	16
Road train 1	> 4.5 m	100	40	28	20	16	75	36	27	19	16	60	33	26	19	16
Road train 2	> 4.5 m	100	40	28	20	16	75	36	27	19	16	60	33	26	19	16
Cars – private	Freeway	110	106	90	72	59	93	90	82	69	58	76	75	71	63	55
Cars – commercial	Freeway	105	99.3	83.3	66.3	54.3	88.7	84.7	76	63.7	53.3	73	71.3	66.7	58.7	51
Non-Articulated	Freeway	99	77.2	58.8	45.4	36.2	82	68.4	55.6	44.2	36	68.6	60.8	51.6	42.8	35.8
Buses	Freeway	110	82	60	46	37	89	73	58	46	37	72	64	54	44	37
Articulated	Freeway	106	53	40	32	24	77	47	39	32	24	60	42	36	31	24
B-double	Freeway	105	41	28	20	16	76	36	27	19	16	60	33	26	19	16
Road train 1	Freeway	105	41	28	20	16	76	36	27	19	16	60	33	26	19	16
Road train 2	Freeway	105	41	28	20	16	76	36	27	19	16	60	33	26	19	16

Source: adapted from Austroads (2005) pages 13-16.

Note:

- < 4.5 m= model road state 1–5
- > 4.5 m= model road state 6–14, 16, 18
- freeway = model road state 15, 17, 19

*Example: Free speed*

A B-double travelling on a curvy road with a gradient of 0%–2% and an MRS of 10 would have an unadjusted free speed of 75 km/h as per Table 4. An MRS of 10 is greater than 4.5 m.

CBA6 provides the option of entering either a default value or a user-specified value for the terrain profile. Free speed is calculated using a weighted average of values relating to the grade selected. The percentage of each grade for each default terrain profile is shown by Table 5.

*Table 5: Terrain grade percentages*

General terrain description	Percentage of each grade				
	Grade factor 1 <2%	Grade factor 2 <4%	Grade factor 3 <6%	Grade factor 4 <8%	Grade factor 5 <10%
Level or flat terrain	90	10	0	0	0
Rolling or undulating	50	30	20	0	0
Mountainous terrain	30	30	20	20	0

Source: TMR.

The free speed formula used in CBA6 is derived as a weighted average of time travelled over a section of road rather than a weighted average of the section length of the road. For more detail, see ARRB research report ARR 279.

*Equation 6: Free speed*

$$Free\ speed\ (VT) = 1 / \sum_i (Grade\%_i / Free\ Speed\ Array\ (VT, Grade_i, HorizAlign, MRS))$$

Where:

- Free speed (VT) = free speed per vehicle type
- Grade% = vertical alignment factors of the road
- Free speed array = corresponding free speed per vehicle type for horizontal alignment and MRS

The formula incorporates the horizontal alignment, vertical alignment and MRS of the road to determine the free speed of each vehicle type.

*Example: Free speed*

The adjusted free speed for a B-double travelling on a curvy flat road with an MRS of 10 is calculated as follows:

$$Free\ speed\ (VT) = 1\ (0.9/75 + 0.1/36)$$

$$Free\ speed\ (VT) = 67.6\ km/h$$

After adjusting for the alignment of the road, the free speed for a B-double changes from 75 km/h to 67.6 km/h.



## 3.2 Roughness adjustment

The values applied to derive the roughness adjustment parameters are listed in Table 6 and Table 7. The values given by the tables for each vehicle type are dependent on the width (< 4.5 m and > 4.5 m), curvature and gradient of the road, similar to the free speed calculation. The road roughness adjustment is weighted on distance rather than time.

Table 6: FSRG1 – Pavement speed condition factor at 110 NRM

Vehicle type	Road type	Straight flat	Straight grad 4%	Straight grad 6%	Straight grad 8%	Straight grad 10%	Curvy flat	Curvy grad 4%	Curvy grad 6%	Curvy grad 8%	Curvy grad 10%	V/curvy flat	V/curvy grad 4%	V/curvy grad 6%	V/curvy grad 8%	V/curvy grad 10%
		Fsrg1	Fsrg1	Fsrg1	Fsrg1	Fsrg1	Fsrg1	Fsrg1	Fsrg1	Fsrg1	Fsrg1	Fsrg1	Fsrg1	Fsrg1	Fsrg1	Fsrg1
Cars – private	< 4.5 m	0.98	0.98	0.99	1	1	0.99	0.99	0.99	1	1	0.99	0.99	0.99	1	1
Cars – commercial	< 4.5 m	0.97	0.98	0.99	1	1	0.98	0.99	0.99	1	1	0.99	0.99	0.99	1	1
Non-Articulated	< 4.5 m	0.95	0.97	0.98	0.99	1	0.97	0.98	0.99	0.99	1	0.98	0.98	0.99	0.99	1
Buses	< 4.5 m	0.97	0.98	0.99	1	1	0.98	0.99	0.99	1	1	0.99	0.99	0.99	1	1
Articulated	< 4.5 m	0.95	0.97	0.99	0.99	1	0.97	0.98	0.99	0.99	1	0.99	0.99	0.99	0.99	1
B-double	< 4.5 m	0.94	0.97	0.99	0.99	1	0.97	0.98	0.99	0.99	1	0.99	0.99	0.99	0.99	1
Road train 1	< 4.5 m	0.94	0.97	0.99	0.99	1	0.97	0.98	0.99	0.99	1	0.99	0.99	0.99	0.99	1
Road train 2	< 4.5 m	0.94	0.97	0.99	0.99	1	0.97	0.98	0.99	0.99	1	0.99	0.99	0.99	0.99	1
Cars – private	> 4.5 m	0.96	0.96	0.98	0.99	1	0.97	0.98	0.99	1	1	0.99	0.99	0.99	1	1
Cars – commercial	> 4.5 m	0.96	0.96	0.98	0.99	1	0.97	0.98	0.99	1	1	0.99	0.99	0.99	1	1
Non-Articulated	> 4.5 m	0.93	0.96	0.98	0.99	1	0.96	0.97	0.98	0.99	1	0.97	0.98	0.99	0.99	1
Buses	> 4.5 m	0.95	0.98	0.99	1	1	0.97	0.98	0.99	1	1	0.99	0.99	0.99	1	1
Articulated	> 4.5 m	0.91	0.96	0.99	0.99	1	0.97	0.98	0.99	0.99	1	0.99	0.99	0.99	0.99	1
B-double	> 4.5 m	0.91	0.96	0.99	0.99	1	0.97	0.98	0.99	0.99	1	0.99	0.99	0.99	0.99	1
Road train 1	> 4.5 m	0.91	0.96	0.99	0.99	1	0.97	0.98	0.99	0.99	1	0.99	0.99	0.99	0.99	1
Road train 2	> 4.5 m	0.91	0.96	0.99	0.99	1	0.97	0.98	0.99	0.99	1	0.99	0.99	0.99	0.99	1

Source: derived by TMR from Austroads (2005) page 18.

Table 7: FSRG2 – Pavement speed condition factor at 250 NRM

Vehicle type	Road type	Road condition														
		Straight flat	Straight grad 4%	Straight grad 6%	Straight grad 8%	Straight grad 10%	Curvy flat	Curvy grad 4%	Curvy grad 6%	Curvy grad 8%	Curvy grad 10%	V/curvy flat	V/curvy grad 4%	V/curvy grad 6%	V/curvy grad 8%	V/curvy grad 10%
		Fsrg2	Fsrg2	Fsrg2	Fsrg2	Fsrg2	Fsrg2	Fsrg2	Fsrg2	Fsrg2	Fsrg2	Fsrg2	Fsrg2	Fsrg2	Fsrg2	Fsrg2
Cars – private	< 4.5 m	0.76	0.77	0.8	0.87	0.92	0.79	0.8	0.83	0.88	0.92	0.84	0.85	0.87	0.9	0.94
Cars – commercial	< 4.5 m	0.75	0.77	0.81	0.88	0.93	0.79	0.8	0.83	0.89	0.93	0.84	0.85	0.87	0.9	0.94
Non-Articulated	< 4.5 m	0.68	0.76	0.84	0.91	0.95	0.74	0.79	0.86	0.91	0.95	0.79	0.83	0.87	0.92	0.95
Buses	< 4.5 m	0.74	0.81	0.89	0.95	0.97	0.79	0.84	0.9	0.95	0.97	0.85	0.87	0.91	0.95	0.97
Articulated	< 4.5 m	0.61	0.78	0.87	0.93	0.97	0.71	0.82	0.89	0.94	0.97	0.81	0.87	0.91	0.94	0.97
B-double	< 4.5 m	0.6	0.79	0.88	0.94	0.97	0.71	0.83	0.89	0.94	0.97	0.81	0.88	0.91	0.95	0.97
Road train 1	< 4.5 m	0.6	0.79	0.88	0.94	0.97	0.71	0.83	0.89	0.94	0.97	0.81	0.88	0.91	0.95	0.97
Road train 2	< 4.5 m	0.6	0.79	0.88	0.94	0.97	0.71	0.83	0.89	0.94	0.97	0.81	0.88	0.91	0.95	0.97
Cars – private	> 4.5 m	0.63	0.65	0.73	0.83	0.9	0.71	0.72	0.77	0.85	0.91	0.81	0.81	0.84	0.88	0.93
Cars – commercial	> 4.5 m	0.64	0.67	0.75	0.85	0.91	0.72	0.74	0.79	0.86	0.92	0.81	0.82	0.85	0.89	0.93
Non-Articulated	> 4.5 m	0.62	0.71	0.83	0.9	0.95	0.7	0.77	0.85	0.91	0.95	0.77	0.82	0.87	0.92	0.95
Buses	> 4.5 m	0.65	0.76	0.88	0.94	0.97	0.75	0.81	0.89	0.95	0.97	0.83	0.86	0.91	0.95	0.97
Articulated	> 4.5 m	0.53	0.74	0.86	0.93	0.97	0.68	0.81	0.88	0.94	0.97	0.8	0.86	0.91	0.94	0.97
B-double	> 4.5 m	0.54	0.75	0.87	0.94	0.97	0.68	0.82	0.89	0.94	0.97	0.8	0.87	0.91	0.95	0.97
Road train 1	> 4.5 m	0.54	0.75	0.87	0.94	0.97	0.68	0.82	0.89	0.94	0.97	0.8	0.87	0.91	0.95	0.97
Road train 2	> 4.5 m	0.54	0.75	0.87	0.94	0.97	0.68	0.82	0.89	0.94	0.97	0.8	0.87	0.91	0.95	0.97

Source: derived by TMR from Austroads (2005) page 18.

The pavement condition speed factor calculation is shown by Equation 7. The roughness array calculation is made at the 110 and 250 NRM.

Equation 7: Free speed roughness array

$$FSRG_i = \sum_i \text{Roughness Array} (VT, \text{Grade}_i, \text{HorizAlign}, \text{MRS}) \times \text{Grade}\%$$

Where:

- FSRGi = pavement condition speed factor at either 110 NRM or 250 NRM

*Example: Free speed roughness array*

For a B-double travelling on a curvy flat road of MRS 10:

$$FSRG1 = \sum_i Roughness\ Array(VT, Grade_i, HorizAlign, MRS) \times Grade\%$$

$$FSRG1 = 0.97 \times 0.9 + 0.98 \times 0.1 + 0.99 \times 0 + 0.99 \times 0 + 1 \times 0$$

$$FSRG1 = 0.97$$

$$FSRG2 = \sum_i Roughness\ Array(VT, Grade_i, HorizAlign, MRS) \times Grade\%$$

$$FSRG2 = 0.71 \times 0.9 + 0.83 \times 0.1 + 0.89 \times 0 + 0.94 \times 0 + 0.97 \times 0$$

$$FSRG2 = 0.69$$

Where:

- FSRG1 = pavement condition speed factor at 110 NRM
- FSRG2 = pavement condition speed factor at 250 NRM

Note: The proportion of section length which falls into each gradient category in CBA6 is illustrated in Table 5.

When current roughness (CNRM) is less than or equal to 110, pavement condition speed factor (pcspdf) is derived by the formula given as Equation 8.

*Equation 8: Pavement condition speed factor at 110NRM*

$$PCSpdF = \begin{cases} CNRM \leq 60 = 1 \\ CNRM \leq 110 = 1 - (1 - FSRG1) \times \frac{(CNRM - PAVC)}{(NRMA1 - PAVC)} \end{cases}$$

Where:

- PCSpdF = pavement condition speed factor
- CNRM = current road roughness in NRM counts per kilometre
- FSRG1 = pavement condition speed factor at 110 NRM
- PAVC = minimum roughness following reconstruction (model parameter = 60)
- NRMA1 = roughness value terminating first linear segment of bilinear relationship (model parameter = 110)

Note: The roughness correction should only apply for CNRM > 60, therefore, pcspdf must equal 1 for CNRM 60. When the CNRM is greater than 110 NRM, the pavement condition speed factor is calculated using Equation 9.

*Equation 9: Pavement condition speed factor greater than 110NRM*

$$PCSpdF = \text{Max} \begin{cases} FSRG1 - (FSRG1 - FSRG2) \times \frac{(CNRM - NRMA1)}{(NRMA - NRMA1)} \\ FSRG2 \end{cases}$$

Where:

- PCSpdF = pavement condition speed factor
- Max = indicates that the larger of the two calculated factors should be selected
- FSRG1 = pavement condition speed factor at 110 NRM
- FSRG2 = pavement condition speed factor at 250 NRM
- CNRM = current road roughness in NRM counts per kilometre
- NRMA = coefficient of the PSR to NRM relationship (model parameter = 250)
- NRMA1 = roughness value terminating first linear segment of bilinear relationship (model parameter = 110)

*Example: Pavement condition speed factor*

A B-double travelling on a curvy flat road at MRS 10 and with a current roughness of 120 NRM.

$$PCSpdF = \text{Max} \left\{ \begin{array}{l} 0.97 - (0.97 - 0.69) \times \frac{(120 - 110)}{(250 - 110)} \\ 0.69 \end{array} \right.$$

$$PCSpdF = \text{Max} \left\{ \begin{array}{l} 0.95 \\ 0.69 \end{array} \right.$$

$$PCSpdF = 0.95$$

As 0.95 is greater than 0.69, the pcspdf used is 0.95.

Corrected free speed is a function of the pavement speed condition factor shown by Equations 8 and 9, and the free speed array calculation shown by Equation 6. The corrected free speed equation for each vehicle type is shown by Equation 10.

*Equation 10: Corrected free speed*

$$\text{Corr Free Speed}(VT) = PCSpdF \times \text{Free Speed}(VT)$$

Where:

- CorrFreeSpeed(VT) = corrected free speed made for roughness
- PCSpdF = pavement condition speed factor
- FreeSpeed(VT) = free speed per vehicle type adjusted for horizontal and vertical alignment and MRS

*Example: Corrected free speed*

The roughness correction factor is now applied to the average free speed calculated previously for the B-double example.

Where:

$$\text{Corr Free Speed (B - Double)} = 0.953 \times 67.67 \text{ km/h}$$

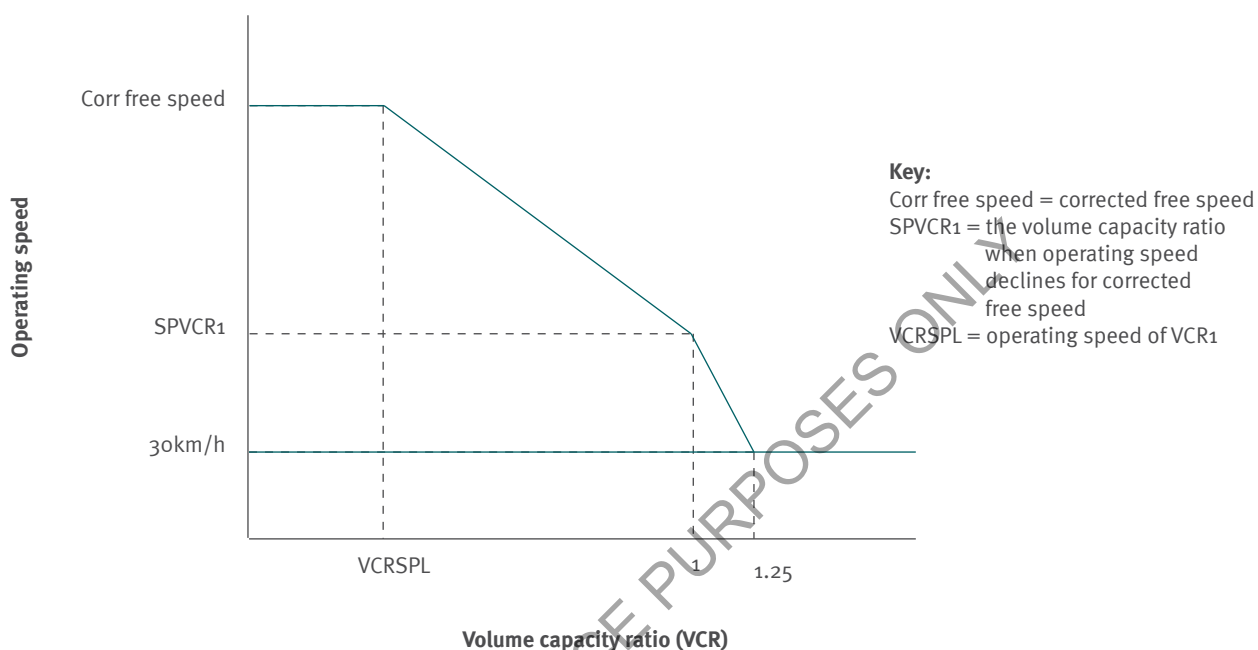
$$\text{Corr Free Speed (B - Double)} = 64.4 \text{ km/h}$$

Therefore the corrected free speed for a B-double travelling on a curvy flat road at MRS 10 and with roughness of 120 NRM.

### 3.3 Congestion adjustment

Once operating speed has been adjusted for roughness, it is then adjusted for congestion. This function adjusts the speed of the fleet according to the level of congestion on the road, which is described by the VCR. The operating speed is plotted as a function of VCR as shown by Figure 2.

Figure 2: Operating speed and VCR of private cars



The vertical axis shown by Figure 2 represents operating speed while the horizontal axis depicts the VCR. The Y-intercept is the corrected free speed which is calculated using Equation 10. When the VCR reaches a value of VCRSPL, the operating speed of the fleet starts to decline to adjust to the growing congestion. The VCRSPL is a parameter value used to represent the VCR level when traffic volume starts to have an effect on the corrected free speed, and vehicle speed declines. As the VCR increases to 1 (the road reaches its theoretical capacity), the speed drops to the corresponding SPVCR1 value. The SPVVCR1 represents the speed at which the fleet can safely travel when capacity is reached. As the VCR increases further to 1.25, the speed drops to the queuing speed of 30km/h. The values of VCRSPL and SPVVCR1 for each MRS are shown by Table 8.

The VCRSPL and SPVVCR1 values are higher for roads with large seal widths and more lanes, than narrow roads with fewer lanes. As the MRS increases, the road is less subject to congestion and speed.

Table 8: Final operating speed parameters

MRS	Road width description	VCRSPL	SPVVCR <sub>1</sub>
1	Unsealed natural surface	0.1	40
2	Unsealed formed road	0.1	40
3	Paved < 4.5 m	0.1	40
4	Paved ≥ 4.5 m	0.1	40
5	Narrow seal ≤ 4.5 m	0.05	40
6	Narrow seal 4.6 m–5.2 m	0.05	50
7	2 lane seal 5.3 m–5.8 m	0.05	65
8	2 lane seal 5.9 m–6.4 m	0.08	65
9	2 lane seal 6.5 m–7.0 m	0.11	65
10	2 lane seal 7.1 m–7.6 m	0.12	65
11	2 lane plus shoulder seal 7.7 m–8.2 m	0.12	65
12	2 lane plus shoulder seal 8.3 m–9.0 m	0.12	65
13	2 lane plus shoulder seal 9.1 m–9.4 m	0.12	65
14	2 lane plus shoulder seal 9.5 m–10 m	0.12	65
15	2 lane plus shoulder seal 10.1 m–11.6 m	0.2	65
16	3 lane for overtaking	0.2	65
17	4 lane undivided sealed	0.3	70
18	6 lane undivided sealed	0.3	70
19	4 lane divided sealed	0.3	70
20	6 lane divided sealed	0.3	70
21	4 lane divided (limited access)	0.4	70
22	6 lane divided (limited access)	0.4	70
23	8 lane divided (limited access)	0.4	70

Source: Austroads (2005) page 22.

The operating speed for private vehicle types calculated by CBA6, is illustrated by Equations 11 to 14. The operating speed for commercial vehicles is dependent on the operating speed of private vehicles and corrected free speed as illustrated by Equation 15.

When  $VCR < VCRSPL$ , the operating speed is given by Equation 11.

*Equation 11: Operating speed when  $VCR < VCRSPL$*

$$OS(VT) = Corr Free Speed (VT)$$

Where:

- $OS(VT)$  = operating speed for each vehicle type

Equation 11 shows that congestion has no effect on the operating speed of the fleet and traffic travels at the corrected free speed. Congestion only starts to affect the operating speed of a private car when the VCR reaches the VCRSPL. The operating speed given by Equation 12 applies when the VCR is less than 1 but greater than VCRSPL.

*Equation 12: Operating speed when VCRSPL VCR 1*

$$OS(VT) = SPVCR1 + (CorrFreeSpeed(VT) - SPVVCR1) \times \left( \frac{(1 - VCR)}{(1 - VCRSPL)} \right)$$

Where:

- SPVCR1 = operating speed at VCR of 1
- VCRSPL = the VCR when operating speed declines from CorrFreeSpeed

Equation 12 shows that as congestion levels increase (VCR approaches 1), operating speed declines to the SPVCR1 operating speed value. When the VCR exceeds this point (1 VCR 1.25), the operating speed is given by Equation 13.

*Equation 13: Operating speed when 1 VCR 1.25*

$$OS(VT) = 30 \text{ km/h} + (SPVCR1 - 30 \text{ km/h}) \times \frac{(1.25 - VCR)}{(1.25 - 1)}$$

In Equation 13, the new operating speed is determined as a function of the SPVCR1 minus a queuing speed of 30 km/h. When the VCR reaches a maximum of 1.25, the operating speed is 30km/h.

Note: Congestion costs per vehicle in CBA6 do not increase once the VCR reaches 1.25. When the VCR is 1.25, operating speed is calculated by the formula given by Equation 14.

*Equation 14: Operating speed when VCR 1.25*

$$OS(VT) = 30 \text{ km/h}$$

Equations 11 to 14 are used for calculating the operating speed of a private vehicle. The operating speed for a commercial vehicle is calculated by Equation 15.

*Equation 15: Commercial operating speed*

$$OS(\text{Commercial } VT) = \text{MIN}(OS(\text{PrivateCar}), \text{Corr Free Speed}(VT))$$

Where:

- MIN = minimum function of equation
- OS (PrivateCar) = operating speed of a private car
- Corr Free Speed (VT) = the corrected free speed of the commercial vehicle

Equation 15 is derived based on the assumption that commercial vehicles should not be able to travel faster than private vehicles.

*Example: Operating speed*

A B-double travelling on a curvy flat road with an MRS 10 and a VCR of 0.058, as calculated in Section 2.4, would have an estimated operating speed calculated as follows:

The calculated VCR < VCRSPL as:

$$VCR = 0.046$$

$$VCRSPL = 0.12$$

Therefore, the operating speed equals the corrected free speed from Equation 11.

$$OS (B - Double) = 64.4 \text{ km/h}$$

Assuming that private vehicle operating speed is above this value, the operating speed for the B-double is 64.4 km/h.

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## 4 Vehicle operating costs

VOC by definition are the costs associated with operating a motor vehicle. VOC are made up of fuel, oil, tyre, repairs and maintenance and interest and depreciation costs. The calculation of each component of VOC is based on a detailed methodology. The calculation of VOC is impacted by a number of inputs and adjustments are made accordingly.

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The inputs and factors that affect VOC calculations in CBA6 are shown by Table 9.

*Table 9: Factors affecting VOC*

Vehicle operating costs	Operating speed	Vehicle characteristics			Road infrastructure		Traffic volume (pce)
		Type and specs	Fuel type	Gradient	Curvature	Surface type and condition	
Fuel	T	T	T	T	T	T	T
Oil	T	T	T				
Tyres	T	T		T	T	T	T
Repairs and maintenance		T				T	
Depreciation and interest	T	T				T	

Source: adapted from Austroads (2005).

The majority of these algorithms and unit values are derived from Austroads report ap-r264/05 'harmonisation of non-urban road user cost models'.

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## 4.1 Fuel

Vehicle fuel cost is calculated based on the fuel consumption of each vehicle. Vehicle operating speed predominantly influences the rate of fuel consumption. Further adjustments to the rate of fuel consumption are made to account for site-specific details such as gradient, curvature, congestion and roughness.

### 4.1.1 Basic fuel consumption

Basic fuel consumption (bfc) and basic fuel cost (fuelcf) are calculated using the parameters given in Table 10. CBA6 applies a unit cost for petrol fuel of 82.49 cents per litre and 81.57 cents per litre for diesel fuel.

Note: Fuel unit values are measured in resources costs and not market/retail prices.

Table 10: Fuel costs and consumption factors

Vehicle type	Square Factor 3	Reciprocal Factor 2	Const. Factor 1	Fcavf State of tune factor	Pdies Proportion of diesel vehicles	Petrol Petrol price (c/litre)	Diesel Diesel fuel price (c/ litre)	Fcong Fuel cons incr factor- VCR=1
Cars – private	0.0054	1526.2	37.3	1.071	0	82.49	81.57	0.4
Cars – commercial	0.0114	1883	38.9	1.071	0	82.49	81.57	0.4
Non- Articulated	0.0168	3485.1	49	1.1	0.5	82.49	81.57	0.3
Buses	0.0131	5451.1	69.4	1.1	0.7	82.49	81.57	0.3
Articulated	0.0158	9621.1	118.6	1.1	0.9	82.49	81.57	0.3
B-double	0.016	14720.4	172.7	1.1	1	0	81.57	0.3
Road train 1	0.0148	17201.8	223.6	1.1	1	0	81.57	0.3
Road train 2	0.015	26646.9	312.1	1.1	1	0	81.57	0.3

Sources: Austroads report 264/5, Austroads report IR-R156/08, CBA4 Technical Manual (1999).

Basic fuel consumption in litres per 1000 km is calculated using Equation 16. Basic fuel consumption is based on the fuel efficiency of each vehicle type and the operating speed.

Equation 16: Basic fuel consumption

$$BFC(VT) = \text{Square}(VT) \times OS^2(VT) + \frac{\text{Reciprocal}(VT)}{OS(VT)} + \text{Constant}(VT)$$

Where:

- BFC(VT) = basic fuel consumption for each vehicle type
- Square(VT) = model parameter
- OS(VT) = operating speed calculation for each vehicle type
- Reciprocal(VT) = model parameter
- Constant(VT) = model parameter

Basic fuel consumption is a function of the default model parameters shown by Table 10. For a graphical representation of the relationship between variables, refer to Figure 12. At this early stage in the fuel consumption calculation, these values will not vary by project location.

*Example: Basic fuel consumption*

Basic fuel consumption in litres per 1000 km for a B-double with an operating speed of 64.4 km/h (as calculated in Section 3) is determined as follows:

$$BFC(VT) = 0.016 \times 64.49^2 + \frac{147,20.40}{64.49} + 172.7$$

$$BFC(VT) = 467.50 \text{ L}/1000\text{km}$$

This shows that at a constant speed of 64.4 km/h, a B-double will consume 467.5 litres of fuel for every 1000 km travelled.

The basic fuel consumption calculation excludes other project-specific factors that affect vehicle fuel consumption. This calculation merely sets the base level from which the actual fuel consumption rate can be determined. The actual fuel consumption in litres per 1000 km is calculated by applying a series of adjustments for gradient, curvature, congestion and roughness.

#### 4.1.2 Fuel consumption gradient correction factors

The gradient adjustment is calculated using the value obtained from the roughness and gradient correction factor values shown by Table 11. The adjustment is made to reflect increased fuel consumption due to a change in gradient. As gradients increase, the adjustment factor also increases, indicating a direct relationship. For example, the gradient adjustment of a private vehicle on a 10% gradient travelling at 40 km/h is 0.30. This indicates that fuel consumption is 30% higher than fuel consumption on a flat road with a grade of less than 4%.

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Table 11: Fuel consumption gradient adjustment array

Vehicle type	Gradient	Speed description												
		Spd_01	Spd_02	Spd_03	Spd_04	Spd_05	Spd_06	Spd_07	Spd_08	Spd_09	Spd_10	Spd_11	Spd_12	Spd_13
		8–15km/h	16–23km/h	24–31km/h	32–39km/h	40–47km/h	48–55km/h	56–63km/h	64–71km/h	72–79km/h	80–87km/h	88–95km/h	96–103km/h	104–112km/h
Cars – private	<4%	0.03	0.07	0.07	0.07	0.08	0.09	0.09	0.10	0.08	0.05	0.04	0.04	0.03
Cars – commercial	<4%	0.02	0.06	0.06	0.05	0.06	0.06	0.07	0.07	0.05	0.04	0.04	0.03	0.03
Non-Articulated	<4%	0.06	0.09	0.08	0.08	0.11	0.16	0.25	0.22	0.18	0.17	0.17	0.17	0.17
Buses	<4%	0.08	0.11	0.10	0.13	0.20	0.26	0.39	0.52	0.42	0.29	0.19	0.10	0.00
Articulated	<4%	0.06	0.14	0.13	0.19	0.28	0.37	0.46	0.46	0.46	0.46	0.46	0.46	0.46
B-double	<4%	0.06	0.15	0.15	0.22	0.31	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
Road train 1	<4%	0.07	0.16	0.15	0.19	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Road train 2	<4%	0.16	0.17	0.13	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Cars – private	<6%	0.04	0.11	0.10	0.11	0.12	0.14	0.17	0.19	0.16	0.12	0.11	0.10	0.08
Cars – commercial	<6%	0.04	0.09	0.09	0.09	0.10	0.11	0.12	0.14	0.11	0.09	0.08	0.08	0.07
Non-Articulated	<6%	0.10	0.18	0.22	0.28	0.34	0.43	0.52	0.47	0.46	0.46	0.46	0.46	0.46
Buses	<6%	0.15	0.24	0.32	0.42	0.54	0.65	0.83	0.98	0.84	0.70	0.57	0.45	0.32
Articulated	<6%	0.18	0.29	0.40	0.52	0.66	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
B-double	<6%	0.10	0.30	0.42	0.54	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
Road train 1	<6%	0.11	0.29	0.39	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Road train 2	<6%	0.39	0.29	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Cars – private	<8%	0.05	0.19	0.17	0.17	0.18	0.21	0.26	0.30	0.25	0.21	0.18	0.15	0.12
Cars – commercial	<8%	0.05	0.17	0.16	0.16	0.17	0.18	0.19	0.22	0.18	0.15	0.13	0.12	0.10
Non-Articulated	<8%	0.19	0.39	0.47	0.55	0.62	0.68	0.70	0.65	0.65	0.65	0.65	0.65	0.65
Buses	<8%	0.26	0.50	0.62	0.76	0.91	1.05	1.25	1.42	1.25	1.08	0.92	0.78	0.62
Articulated	<8%	0.33	0.60	0.75	0.90	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
B-double	<8%	0.18	0.62	0.76	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Road train 1	<8%	0.21	0.61	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Road train 2	<8%	0.60	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
Cars – private	<10%	0.06	0.28	0.27	0.28	0.30	0.35	0.42	0.47	0.42	0.34	0.28	0.25	0.21
Cars – commercial	<10%	0.07	0.27	0.27	0.28	0.30	0.32	0.35	0.39	0.35	0.30	0.26	0.24	0.21
Non-Articulated	<10%	0.30	0.61	0.72	0.83	0.89	0.93	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Buses	<10%	0.39	0.76	0.93	1.11	1.28	1.45	1.69	1.90	1.69	1.49	1.31	1.13	0.95
Articulated	<10%	0.47	0.90	1.08	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
B-double	<10%	0.27	0.93	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12

Road train 1	<10%	0.30	0.91	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01
Road train 2	<10%	0.75	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96

Source: adapted from Austroads (2005) pages 28–29.

The gradient adjustment factor is calculated using Equation 17. This adjustment factor varies by vehicle type, operating speed and the weighted average of the road gradient.

*Equation 17: Fuel consumption gradient adjustment*

$$Grad\ Adjust = \sum_i Gradient\ Adj\ Array(VT, Grade_i, OS) \times Grade\%$$

Where:

- GradAdjust = fuel consumption adjustment factor based on speed and slope
- GradientAdjArray = array table shown by Table 12
- VT = vehicle type
- OS = operating speed (km/h)
- Grade% = slope of the gradient by weighted proportion of road

*Example: Gradient adjustment*

The gradient adjustment for a B-double travelling at the calculated operating speed of 64.4 km/h on flat terrain is calculated as follows:

$$Grad\ Adjust = (0 \times 0.9) + (0.43 \times 0.1) + (0.63 \times 0) + (0.85 \times 0) + (1.12 \times 0)$$

$$Grad\ Adjust = 0.043$$

Therefore, the fuel consumption example calculated in Section 4.1.1 would be adjusted by an increase in consumption of 4.3%.

### 4.1.3 Curvature adjustment

The horizontal alignment of the road can also affect the fuel consumption of vehicles. It is assumed that vehicles consume more fuel on roads with curvy alignments than on straight alignments. The curvature adjustment is calculated using values obtained from Table 12.

Table 12: Fuel consumption curvature adjustment

Vehicle type	Curve categories		
	Very curvy	Curvy	Straight
Cars – private	0.2	0.1	0
Cars – commercial	0.2	0.1	0
Non-Articulated	0.2	0.1	0
Buses	0.2	0.1	0
Articulated	0.2	0.1	0
B-double	0.1	0.1	0
Road train 1	0.1	0.1	0
Road train 2	0.1	0.1	0

Source: adapted from Austroads (2005) page 32.

Note: Values in these columns are applied to the default CBA curvature categories, see Table 17.

The fuel consumption curvature adjustment is shown by Equation 18.

Equation 18: Fuel consumption curvature adjustment

$$\text{Curve Adjust} = \sum_t \text{CurveAdjArray}(VT, \text{CurveCategory})$$

Where:

- CurveAdjust = fuel consumption adjustment factor based on curvature
- CurveAdjArray = see Table 12 for information
- CurveCategory = very curvy, curvy and straight

Example: Curvature adjustment

From Table 12, a B-double travelling on a curvy road will have a curvature adjustment factor of 0.1. A curvy road increases fuel consumption of this vehicle by 10% when compared to a straight road.

#### 4.1.4 Congestion adjustment

The congestion adjustment is calculated using values obtained from the fuel consumption (fcong) parameter in Table 10. Congestion is affected by the rate of fuel consumption of all vehicles, increasing as vehicles remain in congested traffic.

The congestion adjustment is calculated by multiplying the VCR by the fuel consumption factor per vehicle type. The implication of the formula is that some vehicle types consume more fuel in congestion than others. The values in Table 10 indicate that heavy commercial vehicles, which are predominately diesel, use less extra fuel in congested traffic. The congestion adjustment calculation is used in CBA6, if the value calculated is less than 1. If the congestion adjustment calculation is greater than 1, a maximum default value of 1 is used in CBA6. Equation 19 shows the fuel consumption adjustment for congestion.

#### Equation 19: Fuel consumption congestion adjustment

$$\text{Congestion adjustment} = \text{MIN}(1, \text{VCR} \times \text{FCONGF})$$

Where:

- Min = minimum value
- VCR = volume capacity ratio
- FCONGF = fuel consumption adjustment parameter

#### Example: Congestion adjustment

If the VCR is 0.046, the congestion adjustment for a B-double would be calculated as follows:

$$\text{Congestion adjustment} = 0.046 \times 0.3$$

$$\text{Congestion adjustment} = 0.014$$

As the calculated congestion adjustment is less than 1, the calculated congestion adjustment is used. Therefore, fuel consumption of this vehicle increases by 1.4% because of congestion.

### 4.1.5 Roughness adjustment

Adjustments for the effect of road surface condition on fuel consumption are based on road roughness, vehicle type and operating speed.

The first adjustment is the pavement condition cost factor (GCGFAC), which adjusts fuel consumption for the effects of road roughness. This is shown by Equation 20.

#### Equation 20: Fuel consumption pavement condition cost factor

$$\text{GCGFAC} = \text{Min} \left\{ \begin{array}{l} \text{CFSMAX} \\ \text{CSENSP} \times \frac{(\text{CNRM} - \text{PAVC})}{(\text{NRMA} - \text{PAVC})} \end{array} \right.$$

Where:

- GCGFAC = pavement condition cost factor
- CFSMAX = maximum cost factor for surfaced roads and equals 1.75
- CSENSP = cost sensitivity for surfaced roads and equals 4
- CNRM = current roughness of the road
- PAVC = minimum roughness of road after (re)construction (equal to 60)
- NRMA = coefficient of the PSR to NRM conversion ratio (equal to 250)

#### Example: Pavement condition cost

The current roughness of a road is 120 NRM.



$$GCGFAC = \text{Min} \left\{ 4 \times \frac{1.75}{(250 - 60)} = 1.2631 \right.$$

$$GCGFAC = 1.2631$$

The calculated factor is 1.2631 and as the CFSMAX is defaulted to 1.75, the minimum value is applied.

The roughness pavement condition cost factor is adjusted for vehicle type and speed to determine the roughness adjustment factor. The roughness adjustment factor (FCGRVF) is calculated from the roughness correction factors shown by Table 13.

Table 13: FCGRVF fuel consumption roughness adjustment array

Vehicle type	Speed description fcgrvf												
	8-15km/h	16-23km/h	24-31km/h	32-39km/h	40-47km/h	48-55km/h	56-63km/h	64-71km/h	72-79km/h	80-87km/h	88-95km/h	96-103km/h	104-112km/h
Cars – private	0.023	0.060	0.067	0.070	0.077	0.087	0.100	0.103	0.090	0.090	0.090	0.090	0.090
Cars – commercial	0.026	0.060	0.068	0.073	0.078	0.084	0.090	0.092	0.083	0.080	0.080	0.077	0.073
Non-Articulated	0.044	0.083	0.093	0.103	0.111	0.123	0.127	0.110	0.104	0.097	0.091	0.076	0.071
Buses	0.050	0.080	0.090	0.100	0.110	0.120	0.140	0.150	0.130	0.120	0.120	0.110	0.100
Articulated	0.033	0.097	0.113	0.127	0.143	0.160	0.177	0.193	0.187	0.170	0.160	0.147	0.133
B-double	0.050	0.100	0.120	0.140	0.160	0.170	0.190	0.200	0.200	0.220	0.190	0.180	0.170
Road train 1	0.060	0.110	0.130	0.150	0.170	0.190	0.210	0.220	0.240	0.240	0.200	0.200	0.200
Road train 2	0.060	0.120	0.140	0.150	0.170	0.200	0.230	0.270	0.220	0.260	0.230	0.230	0.210

Source: adapted from Austroads (2005) page 31.

A B-double travelling at a speed of 64.4 km/h, is subject to a FCGRVF of 0.2. The roughness adjustment consists of both the FCGRVF and the GCGFAC factors. The roughness adjustment equation is shown below by Equation 21.

#### Equation 21: Fuel consumption roughness adjustment

$$\text{Rough Adj (VT)} = \text{FCGRVF(VT)} \times \text{GCGFAC}$$

Where:

- RoughAdj(VT) = fuel consumption roughness adjustment factor
- FCGRVF(VT) = roughness correction factor

#### Example: Roughness adjustment

For a B-double travelling at a speed of 64.49 km/h, on a road with roughness of 120 NRM, the roughness adjustment factor is:

$$\text{Rough Adj(B - Double)} = 0.2 \times 1.2631$$

$$\text{Rough Adj}(B - \text{Double}) = 0.253$$

This vehicle will incur an increase in fuel consumption of 25.3% due to the impacts of road roughness. This example suggests that road roughness has a significant effect on fuel consumption.

#### 4.1.6 Fuel consumption costs

Using data from Table 10, the cost of fuel in cents per litre is shown by Equation 22. This formula incorporates the weighted average of vehicles depending on their fuel type. For example, a rigid (non-articulated) vehicle may use either petrol or diesel fuel.

*Equation 22: Fuel consumption cost*

$$\text{Fuelcf}(VT) = \text{Petrol}(VT) \times (1 - \text{PDies}(VT)) + \text{Diesel}(VT) \times \text{PDies}(VT)$$

Where:

- Fuelcf (VT) = fuel cost in cents per litre
- Petrol (VT) = cost of petrol in cents per litre
- PDIES (VT) = proportion of diesel vehicles
- DIESEL(VT) = cost of diesel fuel in cents per litre

*Example: Fuel consumption cost*

The fuel cost of a B-double is given below:

$$\text{Fuelcf}(VT) = \text{Petrol}(VT) \times (1 - \text{PDies}(VT)) + \text{Diesel}(VT) \times \text{PDies}(VT)$$

$$\text{Fuelcf}(B - \text{Double}) = 0 \times 0 + 81.57 \times 1$$

$$\text{Fuelcf}(B - \text{Double}) = 81.57$$

The fuel cost for this vehicle is 81.57 cents per litre. Therefore, as all B-double vehicles are assumed to use diesel, the fuel cost is unchanged from the diesel cost in Table 10.

Once the fuel consumption cost has been calculated, it can be incorporated into the total fuel cost formula. Total fuel cost is then adjusted for basic fuel consumption, fuel efficiency, gradient, curvature, congestion and roughness. The total fuel cost is given by Equation 23.

*Equation 23: Total fuel cost*

$$\text{Fuel Cost}(VT) = \text{Fuelcf}(VT) \times \text{BFC}(VT) \times (1 + \text{FCAVF} + \text{Grad Adj} + \text{Curv Adj} + \text{Cong Adj} + \text{Rough Adj})VT$$

Where:

- Fuelcf(VT) = fuel cost in cents per litre
- BFC(VT) = basic fuel consumption
- FCAVF = fuel efficiency or state of tune factor
- Grad Adj = adjustment for the road gradient

- Curve Adj = adjustment for the road curvature
- Cong Adj = adjustment for congestion
- Rough Adj = adjustment for the roughness of the road

Total fuel cost example:

The total fuel cost for a B-double is calculated as follows:

$$\begin{aligned} \text{Fuel Cost}(B - \text{Double}) &= 81.57 \frac{c}{L} \times 467.50 \frac{L}{1000km} \\ &\quad \times (1 + 1.1 + 0.043 + 0.1 + 0.014 + 0.253) \end{aligned}$$

$$\text{Fuel Cost}(B - \text{Double}) = 95,716.277 \text{ c}/1000km$$

$$\text{Fuel Cost}(B - \text{Double}) = 95.72 \text{ c}/km$$

For every kilometre the B-double travels on this road, it will incur fuel costs of 95.72.

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## 4.2 Oil costs

Oil costs are usually a small component of total VOC. Oil consumption is calculated using data in Table 14.

Table 14: Oil costs and consumption factors

Vehicle type	Oil consumption factors (oilcons)													Oil costs	Pdies
	Operating speed													Oils (c/l)	
	8–15km/h	16–23km/h	24–31km/h	32–39km/h	40–47km/h	48–55km/h	56–63km/h	64–71km/h	72–79km/h	80–87km/h	88–95km/h	96–103km/h	104–112km/h		
Cars – private	0.75	0.57	0.53	0.55	0.57	0.60	0.63	0.65	0.67	0.69	0.71	0.74	0.77	522.00	0.00
Cars – commercial	0.75	0.57	0.53	0.55	0.57	0.60	0.63	0.65	0.67	0.69	0.71	0.74	0.77	511.00	0.00
Non-Articulated	1.26	0.99	0.97	0.95	0.96	0.97	0.99	1.01	1.04	1.07	1.13	1.22	1.31	488.00	0.50
Buses	1.26	0.99	0.97	0.95	0.96	0.97	0.99	1.01	1.04	1.07	1.13	1.22	1.31	488.00	0.70
Articulated	1.88	1.37	1.36	1.34	1.36	1.37	1.44	1.50	1.52	1.54	1.56	1.58	1.63	488.00	0.90
B-double	2.59	2.02	1.99	1.98	1.99	2.02	2.07	2.12	2.18	2.23	2.26	2.28	2.34	488.00	1.00
Road train 1	2.59	2.02	1.99	1.98	1.99	2.02	2.07	2.12	2.18	2.23	2.26	2.28	2.34	488.00	1.00
Road train 2	2.59	2.02	1.99	1.98	1.99	2.02	2.07	2.12	2.18	2.23	2.26	2.28	2.34	488.00	1.00

Source: adapted from Austroads (2005) p.35, Austroads (2008) p.16 and pdies

### 4.2.1 Oil consumption

The average oil consumption per vehicle in litres per 1000 km is given by Equation 24.

Equation 24: Average oil consumption

$$Oil(VT) = (dtopcf \times Pdies(VT) + (1 - Pdies(VT)) \times Oilcons(VT, OS) \times gear)$$

Where:

- Oil(VT) = oil consumption averaged over diesel and petrol (litres/1000 km)
- dtopcf = petrol to diesel vehicle conversion ratio (model variable = 1.5)
- Pdies = proportion of vehicles which are diesel powered
- Oilcons(VT, OS) = basic engine oil consumption speed relationship per vehicle
- Gear = factor relating total oil consumption to engine oil use (model variable = 1.1)

Example: Average oil consumption

The average oil consumption per vehicle in litres per 1000 km for a B-double travelling at 64.4 km/h, is given by:

$$Oil(VT) = (dtopcf \times Pdies(VT) + (1 - Pdies(VT)) \times Oilcon(VT, OS) \times gear)$$

$$Oil(B - Double) = (1.5 \times 1 + 1 - 1) \times 2.12 \times 1.1$$

$$Oil(B - Double) = 3.498 L/1000km$$

On average, a B-double will consume 3.498 litres of oil per 1000 km when travelling at a constant speed of 64.4 km/h.

#### 4.2.2 Oil cost

The consumption factor is used to determine the total oil cost for each vehicle, given by Equation 25. The unit oil cost is listed in Table 14 for each vehicle type.

*Equation 25: Total oil cost*

$$OilCost(VT) = Oil(VT) \times Oils(VT)/1000$$

Where:

- OilCost(VT) = the cost of engine oil (c/km)
- Oils(VT) = engine oil price (c/litre)

*Example: Oil cost*

The total cost in cents per kilometre (c/km) for a B-double travelling at 64.4 km/h, with an average oil consumption of 3.498 l/1000 km, is given by:

$$OilCost(B - Double) = 3.498 L/1000km \times 488/1000$$

$$OilCost(B - Double) = 1.71 c/km$$

The total cost of oil for this vehicle is 1.71 cents per kilometre travelled. Compared to the fuel cost example presented in Section 4.1.6, oil costs are a relatively small component of VOC.

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## 4.3 Tyres

Tyre costs in CBA6 are calculated using the data shown by Table 15. The cost of tread wear in cents per 0.001 mm tread thickness (costtread) is calculated first, followed by basic tyre wear which is calculated as 0.001 mm wear per 1000 km. Adjustments are then made for gradient, curvature, roughness and congestion.

Table 15: Tyre wear and cost parameters

Vehicle type	No.tyre	Ctyre#	Cretr#	Retn	Treadn	Treadr	Tyre wc1	Tyre wc2	Tyre k	Tcong^
	Number of tyres (excl. Spares)	Costs of new tyres (\$)	Cost of retreads (\$)	Average number of retreads per tyre	Thickness of tread for new tyre	Thickness of tread for retreaded tyre	Formula factor 1	Formula factor 2	State of tune factor	Factor for tyre wear increase at VCR=1
Cars – private	4	121	66	0	6.71	5.87	0.00000	0.42780	201.9	1.7
Cars – commercial	4	136.33	84.67	0	7.22	6.32	0.00000	0.42780	201.9	1.7
Non-Articulated	7	309.8	141.2	1.4	9.27	8.58	0.00652	0.08556	305.54	1
Buses	8	309.8	141.2	1.75	9.53	8.92	0.00815	0.00000	331.45	1
Articulated	20	338.33	118.67	2.5	10.67	9.75	0.00210	0.00000	100.23	1
B-double	30	331	125	2.5	10.67	9.75	0.00230	0.00000	106.3	1
Road train 1	44	331	130	2.5	10.67	9.75	0.00230	0.00000	106.3	1
Road train 2	62	327	134	2.5	10.67	9.75	0.00230	0.00000	106.3	1

Source: adapted from Austroads (2005) p.39, TMR calculations and Austroads (2008) page 16.

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## 4.4 Tread cost

The calculation of the tread cost (VT) per 0.001 mm thickness is given by Equation 26. The tread cost is a function of the cost of new tyres and the cost of the number and thickness of retreaded tyres. Private and commercial cars do not use retread tyres, as opposed to trucks which it is assumed use both retread and new tyres.

*Equation 26: Tread cost*

$$TreadCost = NoTyre \times \frac{((CTYRE + CRETR \times RETN) \times 100)}{((TREADN + TREADR \times RETN) \times 1000)}$$

Where:

- CTYRE = cost of new tyres (\$)
- CRETR = cost of retreads (\$)
- RETN = average number of retreads per tyre
- TREADN = thickness of tread for new tyre
- TREADR = thickness of tread for retreaded tyre

*Example: Tread cost*

Tread cost for a B-double is given by:

$$Treadcost (B - Double) = 30 \times \frac{((331 + 125 \times 2.5) \times 100)}{((10.67 + 9.75 \times 2.5) \times 1000)}$$

$$Treadcost (B - Double) = 55.07 \text{ c}/0.001\text{mm}$$

Tyre costs for a B-double is 55.07 cents per 0.001 mm of tread. Given the cost of new tyres and the retread costs, heavy vehicles will have the highest tyre costs in the fleet.

### 4.4.1 Tyre wear

The tyre wear formula illustrates the basic speed/tyre wear relationship given by Equation 27. This equation incorporates the operating speed effect, based on the assumption that higher operating speeds increase tyre wear. The example shows that there is a direct relationship between tyre wear and operating speed for private and commercial cars while tyre wear and operating speed for other vehicles exhibit a direct non-linear relationship.

*Equation 27: Basic tyre wear*

$$Tyre\ wear = TyreK(VT) + (OS(VT))^2 \times TyreWC1(VT) + OS(VT) \times TyreWC2(VT)$$

Where:

- Tyrek = state of tune factor
- OS = vehicle operating speed
- TyreWC1 = formula factor 1
- TyreWC2 = formula factor 2

#### Example: Basic tyre wear

Tyre wear for a B-double with operating speed of 64.4 km/h is given by:

$$\text{Tyre Wear}(B - \text{Double}) = 106.30 + 64.49^2 \times 0.0023 + 64.49 \times 0$$

$$\text{Tyre Wear}(B - \text{Double}) = 115.87 \text{ 0.001mm/1000km}$$

Basic tyre wear for a B-double with a constant operating speed of 64.4 km/h is 115.87 (0.001 mm) per 1000 km travelled.

### 4.4.2 Congestion adjustment

Tyre wear is adjusted for congestion levels on the road to calculate the tyre wear congestion adjustment factor for each vehicle type (TCONG). The congestion adjustment is given by Equation 28. The TCONG factor is sourced from Table 15.

#### Equation 28: Congestion adjustment

$$\text{Cong}(VT) = \text{TCONG}(VT) \times \text{VCR}$$

Where:

- Cong(VT) = congestion adjustment factor per vehicle type
- TCONG(VT) = factor for tyre wear increase where VCR = 1 per vehicle type

#### Example: Congestion adjustment

The congestion adjustment value for a B-double on a road with a VCR of 0.046 is given by:

$$\text{Cong}(B - \text{Double}) = 1.0 \times 0.046$$

$$\text{Cong}(B - \text{Double}) = 0.046$$

This result shows that tyre wear increases by 4.6% due to the effect of congestion.

### 4.4.3 Curvature and gradient adjustment

Curvature and gradient adjustments are calculated by the proportion of road sections, which are classified into each curvature and gradient category. These parameter values are shown by Table 16.



Table 16: Curvature and gradient tyre cost adjustments

Vehicle type	Gradient					Curve design speed (km/h)			
	<2%	<4%	<6%	<8%	<10%	30	50	65	80
Cars – private	0	0.1	0.2	0.4	0.6	10	15	20	15
Cars – commercial	0	0.14	0.27	0.54	0.81	10	15	20	15
Non-Articulated	0	0.14	0.27	0.54	0.81	10	15	20	15
Buses	0	0.15	0.3	0.6	0.9	10	15	20	15
Articulated	0	0.15	0.3	0.6	0.9	10	15	20	15
B-double	0	0.15	0.3	0.6	0.9	10	15	20	15
Road train 1	0	0.15	0.3	0.6	0.9	10	15	20	15
Road train 2	0	0.15	0.3	0.6	0.9	10	15	20	15

Source: TMR calculations and adapted from Austroads (2005) p.41

Note: For design speeds greater than those specified in Table 16, CBA6 assumed that the adjustment factor of 0 is used.

Gradient and curvature adjustments in CBA6 are weighted to the proportion of road that is classified by each category. Gradient and curvature proportions used in CBA6 are shown by Table 17.

Table 17: Preset gradient and curvature proportions

Preset	Gradient proportion				
	< 2%	< 4%	< 6%	< 8%	< 10%
Level/flat	90%	10%	0%	0%	0%
Rolling/undulating	50%	30%	20%	0%	0%
Mountainous	30%	30%	20%	20%	0%

Preset	Curvature proportion				
	30km/h	50km/h	65km/h	80km/h	No curve
Straight	0%	0%	0%	10%	90%
Curvy	0%	0%	10%	30%	60%
Very curvy	0%	0%	60%	20%	20%

Source: TMR calculations

Note: CBA6 default gradient settings can be adjusted.

Sections 4.4.3.1 and 4.4.3.2 outline the calculations used to derive the curvature and gradient adjustment factors in CBA6.

#### 4.4.3.1 Gradient adjustment

Gradient adjustment is calculated using data from Table 16 and is shown by Equation 29. The proportion of the road section that is classified by the gradient category is illustrated by Table 17. Subsequently, these values are multiplied to attain the disaggregated gradient adjustment factors.

*Equation 29: Tyre gradient adjustment factor*

$$Grad(VT) = \sum Gradient\ Adj\ Array(VT, Grade_i) \times Grade\%_i$$

Where:

- Grad(VT) = tyre gradient adjustment factor (vehicle type)
- Gradient Adj Array = gradient adjustment values
- Grade% = percentage of road that falls into each category of gradient

*Example: Gradient adjustment*

Gradient adjustment for a B-double on a flat road is given by:

$$Grad(B - Double) = (90\% \times 0.00) + (10\% \times 0.15) + (0\% \times 0.3) + (0\% \times 0.6) + (0\% \times 0.9)$$

$$Grad(B - Double) = 0.00 + 0.015 + 0.00 + 0.00 + 0.00$$

$$Grad(B - Double) = 0.02$$

A flat road, with 90% of the total section with a grade of less than 2% and 10% of the total section at a grade of 4%, increases tyre wear by 2%.

#### 4.4.3.2 Curvature adjustment

Curvature adjustment is calculated in CBA6 using data from Table 16 and is given by Equation 30.

*Equation 30: Tyre curvature adjustment factor*

$$Curv(VT) = \sum Curvature\ Adj\ Array(VT, Design\ Speed_i) \times Curvature\%_i$$

Where:

- Curv(VT) = curvature adjustment factor for tyre wear
- Curvature Adj Array = curvature parameter values
- Curvature%<sub>i</sub> = percentage of road that falls into each category of curvature

*Example: Curvature adjustment*

The curvature adjustment for a B-double on a curvy road is given by:

$$Curv(B - Double) = (0\% \times 10) + (0\% \times 15) + (10\% \times 20) + (30\% \times 15) + (60\% \times 0)$$

$$Curv(B - Double) = (0.1 \times 20) + (0.3 \times 15) + (0.6 \times 0)$$

$$Curv(B - Double) = 6.5$$

Tyre costs incurred on a curvy road are 6.5 times higher than on a straight road. The curvature adjustment factor accounts for the greatest change in tyre wear.

#### 4.4.4 Roughness adjustment

The roughness adjustment for tyre wear is dependent on operating speed and is shown by Table 18.

Table 18: Tyre roughness adjustment array

Vehicle type	Operating speed (km/h)										
	8–16	16–24	24–32	40–48	48–56	56–64	64–72	72–80	80–88	88–96	96–104
Cars – private	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Cars – commercial	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Non-Articulated	0.32	0.32	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.30	0.30
Buses	0.28	0.28	0.28	0.28	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Articulated	0.17	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.18	0.18	0.18
B-double	0.19	0.19	0.19	0.19	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Road train 1	0.19	0.19	0.19	0.19	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Road train 2	0.19	0.19	0.19	0.19	0.20	0.20	0.20	0.20	0.20	0.20	0.20

Source: adapted from Austroads (2005) p.40

The roughness adjustment value is selected from the tyre roughness adjustment array based on the current operating speed of the vehicle.

#### Example: Roughness adjustment example

The roughness adjustment for a B-double travelling at 64.4 km/h is 0.2, which indicates that the road roughness increases tyre wear by 20%.

#### 4.4.5 Total unit tyre cost

The total tyre unit cost represents the total tyre usage cost adjusted for the road characteristics, as shown by Equation 31.

#### Equation 31: Tyre cost

$$Tyres(VT) = TreadCost \times btw(VT) \times (1 + Cong(VT) + Curve(VT) + Rough(VT) + Grad(VT))$$

Where:

- Tyres(VT) = tyre cost
- btw(VT) = basic tyre wear

#### Example: Tyre cost

For a B-double, the total unit cost is shown by the aggregate of the individual calculations as follows:

$$Tyres(B - Double) = 55.07 \times 115.87 \times (1 + 0.046 + 6.5 + 0.2 + 0.02)$$

$$Tyres(B - Double) = 49580.067 \text{ c}/1000\text{km}$$

$$Tyres(B - Double) = 49.58\text{c}/\text{km}$$

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## 4.5 Repairs and maintenance

Repairs and maintenance costs are calculated using the road roughness and basic repairs and servicing costs as shown by Table 19. This table shows the basic repairs and servicing costs for all vehicle types per kilometre travelled. Unlike other operating cost components, speed, road alignment and traffic congestion do not directly affect vehicle repairs and maintenance costs.

Table 19: Repairs and servicing cost (RMUC)

Vehicle type	RMUC
	Basic repairs and servicing cost (cents/km)
Cars – private	4.5
Cars – commercial	4.6
Non-Articulated	8.6
Buses	8.6
Articulated	16.6
B-double	20.6
Road train 1	22.0
Road train 2	28.2

Source: adapted from Austroads (2008) page 16.

### Example: Repairs and service cost

The basic repairs and servicing cost for a B-double is 20.6 c/km.

The basic servicing and repairs costs are adjusted for pavement condition via the pavement condition index (pavind), in Table 20.

Table 20: Pavement condition index

Surface type	Pavind (NRM)				
	50	100	150	200	250
Earth/formed	3.5	3.5	3.5	3.5	3.5
Gravel	1.5	1.57	1.65	2	2.5
Sealed/concrete	1	1.15	1.3	1.45	1.6

Source: adapted from Austroads (2005) page 47.

Parameter values are given for 50, 100, 150, 200 and 250 NRM. These pavement condition values need to be interpolated to attain a parameter corresponding to current roughness (CNRM).

Note: The current roughness should lie between 30 and 250 NRM. When the current roughness is less than 50 NRM, the adjustment value or rscmr factor will be equal to 1 as shown by Equation 32.

Equation 32: Repairs and maintenance adjustment factor

$$rscmrf(VT) \begin{cases} 30 \leq CNRM < 50 = 1 \\ 50 \leq CNRM < 100 = 1 + (PAVIND(ST, 100) - PAVIND(ST, 50)) \frac{(CNRM - 50)}{(100 - 50)} \\ 100 \leq CNRM < 150 = PAVIND(ST, 100) + (PAVIND(ST, 150) - PAVIND(ST, 100)) \frac{(CNRM - 100)}{(150 - 100)} \\ 150 \leq CNRM < 200 = PAVIND(ST, 150) + (PAVIND(ST, 200) - PAVIND(ST, 150)) \frac{(CNRM - 150)}{(200 - 150)} \\ 200 \leq CNRM < 250 = PAVIND(ST, 200) + (PAVIND(ST, 250) - PAVIND(ST, 200)) \frac{(CNRM - 200)}{(250 - 200)} \end{cases}$$

Where:

- CNRM = current roughness in NRM
- PAVIND(PT) = pavement index value at the current surface type (ST)

Example: Repairs and maintenance adjustment factor

For a B-double on a sealed road with a current roughness of 120 NRM, the calculation is as follows:

$$rscmrf(B - Double) = 1.15 + (1.3 - 1.15) \times \frac{(120 - 100)}{(150 - 100)}$$

$$rscmrf(B - Double) = 1.21$$

The repairs and maintenance costs for a B-double travelling on a road would increase by 21% if the roughness was increased from below 50 NRM to 120 NRM.

#### 4.5.1 Total repairs and maintenance unit cost

The unit repairs and maintenance cost for this VOC component is the sum of the basic repairs and maintenance cost per vehicle type and the roughness adjustment factor shown by Equation 33.

Equation 33: Repairs and maintenance cost

$$REPMCS(VT) = RMUC(VT) \times rscmrf(VT)$$

Where:

- REPMCS(VT) = repairs and maintenance cost per vehicle type
- RMUC(VT) = basic repairs and maintenance cost per vehicle type
- rscmrf(VT) = repairs and maintenance adjustment factor per vehicle type

Example: Repairs and maintenance cost

The total repairs and maintenance costs for a B-double are given by:

$$REPMCS = RMUC \times rscmrf$$

$$REPMCS = 20.6 \times 1.21$$

*REPMCS = 24.93 c/km*

The repairs and maintenance costs for a B-double travelling on a 120 NRM road surface would incur a repairs and maintenance cost of 24.93 cents per kilometre travelled.

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## 4.6 Depreciation and interest costs

Depreciation and interest costs for all vehicle types are calculated using the data shown by Table 21.

Table 21: Time and depreciation factors

Vehicle type	Tax	Vehicles	Ddpn	Tdi	Fleet	Ahour
	Effective sales tax % on new vehicles	New vehicle price (\$)	Basic distance depreciation rate	Basic time depreciation	Proportion of VT susceptible to fleet reduction	No. Of hours/year vehicle is available on the road
Cars – private	10%	24,410	0.22	9.50	0.00	1000
Cars – commercial	10%	29,890	0.25	9.20	0.27	1200
Non-Articulated	10%	101,450	0.28	7.40	0.80	1760
Buses	10%	101,450	0.15	7.00	0.80	2000
Articulated	10%	245,917	0.15	5.50	0.65	2833
B-double	10%	357,110	0.14	5.50	0.60	3000
Road train 1	10%	395,720	0.14	5.50	0.60	3000
Road train 2	10%	495,950	0.14	5.50	0.60	3000

Source: adapted from Austroads (2008) page 16 and Austroads (2005) page 51

The values from Table 22 are used to calculate the net depreciation and interest costs. These values describe the relationship between distance depreciation and road surface type.

Table 22: Surface type factor

Surface type	Depsrf
Factor relating distance depreciation to road surface type	
Unsurfaced	2.5
Primerseal	1.5
Sealed	1
Concrete	1

Source: TMR.

The distance and time depreciation per vehicle type is derived to calculate the net depreciation and interest costs. The economic cost of a new vehicle is calculated and then adjusted to account for distance and time.

### 4.6.1 Economic cost of a new vehicle

A component of the depreciation and interest calculations is the economic cost of a new vehicle. This is defined as the price of the vehicle less the cost of all tyres supplied with the vehicle including any spares. The economic cost of a new vehicle is shown by Equation 34, where price calculations are net of sales tax.

Equation 34: Economic cost of a new vehicle

$$ECV(VT) = VEHICLES(VT) \times \left( \frac{100}{100 + TAX(VT)} \right) - CTYRE(VT) \times (NOTYRE(VT) + 1)$$



Where:

- $ECV(VT)$  = economic cost of the vehicle
- $VEHICLESS(VT)$  = new vehicle price per vehicle type (\$)
- $TAX$  = effective sales tax on new vehicles
- $NOTYRE(VT)$  = number of tyres (including spares)
- $CTYRE(VT)$  = cost of new tyres (\$)

*Example: Economic cost of a new vehicle*

For a B-double, the economic cost of a new vehicle is:

$$ECV = 357110 \times \left( \frac{100}{100 + 10\%} \right) - 331 \times (30 + 1)$$

$$ECV = \$346,492.25$$

The economic cost of a new B-double including sales tax and the number of tyres is \$346 492.

#### 4.6.2 Basic distance depreciation

Basic distance depreciation (cents/km) is derived from the economic cost of a new vehicle and a distance depreciation rate. Basic distance depreciation is shown by Equation 35.

*Equation 35: Basic distance depreciation*

$$DSTDEP(VT) = 0.001 \times 100 \times ECV(VT) \times \frac{DDPN(VT)}{100}$$

Where:

- $DSTDEP$  = basic distance depreciation (cents/km)
- $ECV(VT)$  = economic cost of new vehicle (\$)
- $DDPN(VT)$  = distance depreciation rate %

*Example: Basic distance depreciation*

For a B-double, the distance depreciation is:

$$DSTDEP (B - Double) = 0.001 \times 100 \times 346,492.25 \times \frac{0.14}{100}$$

$$DSTDEP (B - Double) = 48.51 \text{ c/km}$$

The economic value of a new B-double will depreciate by 48.51 cents for every kilometre travelled.

#### 4.6.3 Time depreciation

Basic time depreciation is derived as a function of the economic cost of a new vehicle, which is shown by Equation 36.

#### Equation 36: Basic time depreciation

$$TDPINT(VT) = 100 \times ECV(VT) \times \left( \frac{TDI(VT)}{100} \right) \times \frac{FLEET(VT)}{AHOUR(VT)}$$

Where:

- TDPINT(VT) = marginal time depreciation and interest per vehicle type (cents/hour)
- ECV(VT) = economic cost of new vehicle per vehicle type (\$)
- TDI(VT) = basic time depreciation and interest rate per vehicle type (%/year)
- FLEET(VT) = proportion of vehicle type susceptible to 'fleet reduction' effects due to travel time reduction per vehicle type
- AHOUR(VT) = number of hours a year for which vehicle type is available 'on the road' per vehicle type

#### Example: Basic time depreciation

For a B-double, time depreciation is:

$$TDPINT(B - Double) = 100 \times 346,492.25 \times \left( \frac{5.5}{100} \right) \times \frac{0.6}{3000}$$

$$TDPINT(B - Double) = 381.14 \text{ c/hr}$$

This value represents a depreciation rate of 381.14 cents for every hour the vehicle is on the road in addition to the distance depreciation.

### 4.6.4 Net depreciation and interest costs

Net depreciation and interest costs combine both time and distance components, shown by Equation 37.

#### Equation 37: Net depreciation and interest

$$DPINCS(VT) = \left( DSTDEP(VT) \times DEPSRF + \frac{TDPINT(VT)}{OS(VT)} \right)$$

Where:

- DPINCS(VT) = depreciation and interest costs per vehicle type (cents/km)
- DSTDEP(VT) = basic distance depreciation (VT)(cents/km)
- DEPSRF = factor relating distance depreciation to road surface type (VT)
- TDPINT(VT) = marginal time depreciation and interest per vehicle type (cents/hour)
- OS(VT) = operating speed

#### Example: Depreciation and interest

For a B-double travelling at 64.4 km/h on a sealed road, the net depreciation and interest cost is:

$$DPINCS(B - Double) = \left( 48.51 \times 1.0 + \frac{381.14}{64.49} \right)$$

$$DPINCS(B - Double) = 54.42 \text{ c/km}$$

This figure incorporates both the hourly and distance rates into a single per kilometre depreciation rate.

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## 4.7 Total unit vehicle operating cost

The total unit VOC is the sum of the individual VOC components calculated throughout Section 4. This includes fuel, tyres, oil, repairs and maintenance, and interest and depreciation. Total unit VOC are given in Equation 38.

*Equation 38: Total unit VOC*

$$\text{UnitVOC}(VT) = \text{Fuel} + \text{Oil} + \text{Tyres} + \text{Repairs} + \text{Depreciation}$$

Where:

- UnitVOC(VT) = unit vehicle operating cost (cents/km)

*Example: Total unit VOC*

In the B-double, this would be as follows:

$$\text{UnitVOC}(B - \text{Double}) = 95.72 + 1.71 + 49.58 + 24.93 + 54.42$$

$$\text{UnitVOC}(B - \text{Double}) = 226.36 \text{ c/km}$$

The total unit vehicle operating cost for the B-double is 226.36 cents per kilometre travelled.

The total VOC for the year is then summed across all vehicle types. The VOC formula is shown by Equation 39.

*Equation 39: Total VOC (all vehicle types)*

$$\text{TotalVOC} = \text{Seclength} \times \text{days} \times \sum_i \text{AADT}_i \times \frac{\text{VOC}_i}{100}$$

The VOC calculation is completed for each year of the evaluation. The VOC value will change as road conditions such as roughness and volume vary each year.

The annual VOC derivation is required for both the base and project cases. The difference between the VOC derived for the base case and project case will be used to estimate the annual and total VOC benefit for the proposed project.



4

## 5 Travel time costs

TTC are the monetised costs to the road user for the time taken to complete a journey. TTC benefits equal the difference in road user TTC between the base case and the project case. TTC are a function of trip time, average occupancy per vehicle, the monetary value of time per occupant, cost of freight delay per hour and AADT.

The calculation of trip time is shown by Equation 40.

*Equation 40: Trip time*

$$\text{TripTime}(VT) = \frac{\text{SecLength}}{\text{OS}(VT)}$$

Where:

- TripTime(VT) = trip time (hours)
- SecLength = section length (km)
- OS(VT) = operating speed

*Example: Trip time*

For a B-double travelling along a sealed, 5 km road section at 64.4 km/h, the trip time is:

$$\text{TripTime}(B - \text{Double}) = \frac{5\text{km}}{64.4\text{km/h}}$$

$$\text{TripTime}(B - \text{Double}) = 0.0775 \text{ hrs (4.65 minutes)}$$

The 5 km journey takes 4.65 minutes to complete when travelling at an average speed of 64.4 km/h.

Note: Trip time will differ for each vehicle type based on operating speed as calculated in Section 3.

Each vehicle type has an associated cost reflecting the value of the occupant's time and the cost of freight delays. These costs differ between urban and rural speed environments as the occupancy rates change between environments. These time costs are shown by Table 23.

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Table 23: Estimated values of travel time – occupant and freight payload values

Vehicle type	Environment	Resource prices (June 2007)			
		Value per occupant (pers/hr)	Freight travel time (value per veh-hour)	Occupancy rate (pers/veh)	Total value of time (\$/veh.hr)
Cars – private	Rural	11.49	0.00	1.70	19.53
	Urban	11.49	0.00	1.60	18.38
Cars – commercial	Rural	32.01	0.00	1.30	41.62
	Urban	32.01	0.00	1.40	44.81
Non-Articulated	Rural	22.86	2.67	1.17	29.35
	Urban	22.86	5.26	1.20	32.69
Buses	Rural	11.49	0.00	12.00	137.88
	Urban	11.62	0.00	15.00	174.30
Articulated	Rural	23.76	15.00	1.00	38.76
	Urban	23.76	29.54	1.00	53.30
B-double	Rural	23.87	24.53	1.00	48.40
	Urban	24.98	48.32	1.00	73.30
Road train 1	Rural	24.98	32.79	1.00	57.77
	Urban	26.11	0.00	1.00	26.11
Road train 2	Rural	25.44	48.32	1.00	73.76
	Urban	25.44	0.00	1.00	25.44

Source: adapted from Austroads (2008) page 18.

The final derivation of annual travel time value per vehicle and vehicle type is given by Equation 41.

#### Equation 41: Annual travel time

$$TTC(VT) = AnnFact \times (TripTime(VT) \times AADT_{(VT)} \times VTVEHR(VT))$$

Where:

- $TTC(VT)$  = TTC cost (\$)
- AnnFact = annualisation factor (days per year)
- TripTime(VT) = trip time (hrs)
- VTVEHR = value of time per vehicle (\$)
- $AADT(VT)$  = annual average daily traffic of vehicles type x

#### Example: Travel time cost

For a B-double travelling 4.65 minutes on a rural road, the annual time cost is:

$$TTC(VT) = 365.25 \times (0.0775 \times 1 \times 48.40)$$

$$TTC(VT) = \$1370.05 \text{ per year}$$

The TTC for a B-double is \$1370.05 per year.

This TTC calculation is repeated for each year of the assessment as a number of variables will change with road and traffic conditions, including congestion and trip time.

AADT in this example refers to the number of vehicles for each vehicle type, instead of the aggregate value. In calculating the total TTC, these calculations would be summed for each vehicle type in both base and project cases.

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# 4

## 6 Accident costs

Accident costs are calculated using a default accident rate based on road type and the average cost of a crash. CBA6 calculates the accident cost from estimations of average crash costs based on the crash severity and historical crash rates determined by the modal road state (MRS).

Accident costs are a Queensland average, based on Austroads unit crash data. Unit costs used in CBA6 are shown by Table 24. Values calculated in this table are derived using the human capital approach rather than willingness to pay. For more detail see Section 2.2.3 of the *Theoretical Guide*.

Table 24: Unit costs per crash type for Queensland

	Fatal injury	Serious injury	Minor injury	Average casualty	Property damage
Rural	2 102 000	502 000	20 200	259 000	7 500
Urban	1 958 000	471 000	20 600	183 000	7 500

Source: Adapted from Austroads (2008), page 21.

Unit costs per crash type are weighted according to frequency of occurrence in Queensland. The breakdown of the severity of road crashes in 2005 is shown by Table 25.

Table 25: Severity of road crashes in Queensland (2005)

		Fatal injury	Serious injury	Other injury	Property damage	Total
Rural	Number of crashes	153	1 051	1 193	1 462	3 859
	Number killed	174				
	Number serious injuries	76	1 332			
	Number other injuries	22	229	1 535		
	Number no injuries	N/A	N/A	N/A		
Urban	Number of crashes	143	4 067	7 246	7 682	19 138
	Number killed	156				
	Number serious injuries	37	4 842			
	Number other injuries	32	739	9 059		
	Number no injuries	N/A	N/A	N/A		
Total	Number of crashes	296	5 118	8 439	9 144	22 997
	Number killed	330				
	Number serious injuries	113	6 174			
	Number other injuries	54	968	10 594		
	Number no injuries	N/A	N/A	N/A		

Source: Table c3, Austroads (2008) page 56.

Costs per crash are stored in CBA6 as shown by Table 26.

Table 26: Average crash costs

Crash type	Rural	Urban
Fatal injury	\$2 102 000	\$1 958 000
Serious injury	\$502 000	\$471 000
Other injury	\$20 200	\$20 600
Property damage	\$7 500	\$7 500
Average crash cost	\$229 145	\$125 532

Source: TMR calculations.

Table 26 shows that average crash costs calculated for individual casualty crash categories can vary across areas of operation. Severity of crashes tend to increase with vehicle operating speeds as a greater proportion of people are killed or seriously injured in higher speed environments than lower speed environments. As a result, average crash costs in rural areas are higher than for urban areas.

To determine the casualty crash rate for a rural road, the casualty crash rate for a two-lane road with a 7 m seal is used as a base for deriving the casualty crash rate for alternative road types. The rural road crash rate is shown by Equation 42.

Equation 42: Rural crash rate

$$A_{CR} = K_{MRS}K_{HA}AB_{CR}$$

Where:

- $A_{CR}$  = predicted casualty crashes per MVKT for a road of given attributes
- $AB_{CR}$  = casualty crash rates for a two-lane road with a 7 m seal and nom curves of speed standard 90 km/h or less is estimated at 0.25 crashes per MVKT
- $K_{MRS}$  = factor to derive crash rates for road standards different from the ABCR value, with no curves of 90 km/h or less
- $K_{HA}$  = factor to modify predicted crash rates for roads with horizontal alignment of speed standard 90 km/h or less

Note: the  $K_{HA}$  factor is not currently used in CBA6.

Casualty crashes in CBA6 are factored up to the total crash rate as indicated by Equation 43.

Equation 43: Crash rate

$$A_{TR} = \frac{A_{CR}}{P_{CAS}}$$

Where:

- $A_{TR}$  = predicted total crash per MVKT for a given road of given attributes
- $P_{CAS}$  = proportion of casualty crashes in recorded rural crashes (0.568)

(Calculated from TMR databases from 1996–2001.)

The default crash rates applied in CBA6 to each MRS are shown by Table 27.

Table 27: Crash rate per MRS

MRS	Road width description	KMRS *	Acr – rural casualty crash rate/MVKT	Atr – accidents per MVKT
1	Unsealed natural surface	1	0.25	0.440140845
2	Unsealed formed road	1	0.25	0.440140845
3	Paved < 4.5 m	1.4	0.35	0.616197183
4	Paved ≥ 4.5 m	1.4	0.35	0.616197183
5	Narrow seal ≤ 4.5 m	1.2	0.3	0.528169014
6	Narrow seal 4.6 m–5.2 m	1.56	0.39	0.686619718
7	2 lane seal 5.3 m–5.8 m	1.6	0.4	0.704225352
8	2 lane seal 5.9 m–6.4 m	1.3	0.325	0.572183099
9	2 lane seal 6.5 m–7.0 m	1	0.25	0.440140845
10	2 lane seal 7.1 m–7.6 m	0.86	0.215	0.378521127
11	2 lane plus shoulder seal 7.7 m–8.2 m	0.74	0.185	0.325704225
12	2 lane plus shoulder seal 8.3 m–9.0 m	0.64	0.16	0.281690141
13	2 lane plus shoulder seal 9.1 m–9.4 m	0.58	0.145	0.25528169
14	2 lane plus shoulder seal 9.5 m–10 m	0.52	0.13	0.228873239
15	2 lane plus shoulder seal 10.1 m–11.6 m	0.47	0.118	0.206866197
16	3 lane for overtaking	N/A	N/A	N/A
17	4 lane undivided sealed	0.85	0.213	0.374119718
18	6 lane undivided sealed	0.85	0.213	0.374119718
19	4 lane divided sealed	0.45	0.113	0.19806338
20	6 lane divided sealed	0.45	0.113	0.19806338
21	4 lane divided (limited access)	0.275	0.069	0.121038732
22	6 lane divided (limited access)	0.275	0.069	0.121038732
23	8 lane divided (limited access)	0.275	0.069	0.121038732

Source: Austroads (2001).

Note: The accident crash rate is not applicable to MRS 16 as MRS 16 includes an overtaking lane. Accident cost benefits for overtaking lanes can be found in Section 8.

## 6.1 Total crash cost

The total crash cost in monetary terms is given by Equation 44. The total crash cost calculation is determined by the number of vehicles on the road, the accident rate and the average crash cost.

*Equation 44: Total crash cost*

$$CrashCost_{RT} = MVKT \times A_{TR} \times AACCR_{RT}$$

$$CrashCost = \frac{AADT \times 365.25 \times SecLength}{1,000,000} \times A_{TR} \times AACCR_{RT}$$

Where:

- AADT = annual average daily traffic (vehicles)
- SecLength = section length (km)
- $A_{TR}$  = total crash rate (accident/MVKT)
- $AACCR_{RT}$  = average crash cost for road type (\$)

*Example: Crash cost*

The crash cost for a thousand vehicles travelling along a 10 km, rural two-lane road with a shoulder seal (MRS 11) is:

$$CrashCost_{RT} = \frac{1000 \times 365.25 \times 10}{1,000,000} \times 0.325704225 \times \$229,145$$

$$CrashCost_{RT} = 3.6525 \times 0.325704225 \times 229,145$$

$$CrashCost_{RT} = \$272,598.84/\text{year}$$

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## Percentage reduction in accidents for intersection treatments, low speed environment – two vehicle accidents

Accident Group Number	Two vehicle accidents										
	1	2	3	4	5	6	7	8	9	10	11
DCA Codes	101-109	201-501	202-206	207-304	301-303	305-307	308-309	401-409	503-506	601	903
Accident Costs (2007 prices)	\$78 100	\$178 300	\$77 300	\$38 800	\$60 600	\$54 200	\$74 100	\$54 900	\$73 400	\$55 000	\$216 700
Roundabout - 1 lane	70	70	60	50	30			20			
Roundabout - 2 lane	70	70	60	50	30			20			
New traffic signals - filter turns allowed	60		-30		-40						
New traffic signals - no filter turns allowed	60		90		-40						
Street closure - cross intersection	70	50	70		50						
Street closure - T intersection	100	50	100		50						
Grade separation of intersection	100		100				50				
Median closure	100		100	100	50						
Stagger cross intersection	50	50	50								
Seagull island without acceleration lane - raised island	10	40	40	15	60	40	40		70		
Seagull island without acceleration lane - painted island	20	40	40	15	60	40	40		70		
Seagull island without acceleration lane - painted island	10	40	40	15	60	40	40		70		
Seagull island without acceleration lane - painted island	20	40	40	15	60	40	40		70		
New signing stop	50				-50						
New signing give way	10										
New signing prohibit turns	70		70		70		70				
Fully control right turn with arrows			80								
Introduce right turn phase while leaving filter			-10								
Red light camera at existing traffic signals	30		25		-30						
Upgrade signal display (mast arm/additional lanterns)	20		10		25						
Protected right turn lane	15		40		60	40	40		70		
Protected right turn lane	15		40		60	40	40		70		
Left turn acceleration lane			25		60	40	40				
Separate left turn acceleration lane	10		15		60	40	40				
Install additional priority signals	30										
Move limit lines forward using paint markings	10										
New signing - intersection warning	15				25	10					
Move limit lines forward using curb extensions	25										

### Accident Group Description

- |                                      |                               |                                 |
|--------------------------------------|-------------------------------|---------------------------------|
| 1 Intersection - adjacent approaches | 8 Manoeuvring                 | 15 Off carriageway - hit object |
| 2 Head-on                            | 9 Overtaking - same direction | 16 Off straight - hit object    |
| 3 Opposing vehicles                  | 10 Hit parked vehicle         | 17 Out of control straight      |
| 4 U-turn                             | 11 Hit railway train          | 18 Off carriageway - curve      |
| 5 Rear-end                           | 12 Hit pedestrian             | 19 Off curve - hit object       |
| 6 Lane change                        | 13 Permanent obstruction      | 20 Out of control - curve       |
| 7 Parallel lanes - turning           | 14 Hit animal                 |                                 |

**Percentage reduction in accidents for intersection treatments, low speed environment –one vehicle accidents**

Accident Group Number	Single vehicle accidents									
	12	13	14	15	16	17	18	19	20	
DCA Codes	001-008, 901-902	605	609	701-702,502, 706-709	703-704	705,502	801-802	803-804	805	
Accident Costs (2007 prices)	\$164 600	\$74 900	\$40 300	\$60 600	\$116 200	\$84 400	\$102 700	\$102 700	\$87 700	
Roundabout - 1 lane	10									
Roundabout - 2 lane	-20									
New traffic signals - filter turns allowed	0									
New traffic signals - no filter turns allowed	10									
Street closure - cross intersection	30									
Street closure - T intersection	40									
Grade separation of intersection	70									
Median closure										
Stagger cross intersection	50									
Seagull island without acceleration lane - raised island	25									
Seagull island without acceleration lane - painted island	25									
Seagull island without acceleration lane - painted island	25									
Seagull island without acceleration lane - painted island	25									
New signing stop	10									
New signing give way										
New signing prohibit turns										
Fully control right turn with arrows										
Introduce right turn phase while leaving filter										
Red light camera at existing traffic signals										
Upgrade signal display (mast arm/additional lanterns)										
Protected right turn lane										
Protected right turn lane										
Left turn acceleration lane										
Separate left turn acceleration lane										
Install additional priority signals										
Move limit lines forward using paint markings										
New signing - intersection warning										
Move limit lines forward using curb extensions										

Note: Costs are based on the costs contained in “Crash costs 2001: cost by accident type” produced by Dr David Andreassen of Data Capture and Analysis, factored up by 2.393% for 6 years and rounded to the nearest \$100. DCA codes, in TMR, are predominantly limited to the evaluation of accident cost savings at intersections. The columns in the table represent the percentage reduction in accidents of a particular nature from a prescribed treatment. For example, introducing a stop sign will reduce accidents from intersection, adjacent approaches by 50% and accidents involving pedestrians by 10% but increase rear-end accidents by 50%. If we assume an annual average of 4 accidents from intersection, adjacent approaches, 6 accidents from rear-end collisions and 1 accident involving a pedestrian at a particular intersection, the annual undiscounted accident cost savings from implementing the stop sign at this intersection =  $4 \times 0.5 \times \$78,100 + 6 \times (-0.5) \times \$38,800 + 1 \times 0.1 \times \$164,600 = \$56,260$  in Year 1. The following years' savings can be calculated by multiplying the Year 1 savings by the traffic growth rate.



# 4

## 7 Externalities

This section of the *Technical Guide* explains the calculation of externality costs for transport infrastructure projects. Externality costs are calculated outside CBA6. The manual calculation is entered as a dollar value per year in the 'accident and other costs' screen, see Section 3.7 of the *User Guide*. The theories supporting the calculation of externalities are covered extensively in Chapter 3 of the *Theoretical Guide*.

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Externality costs are calculated based on VKT for passenger and bus vehicle types and 1000 tonne kilometres (1000 t/km) for light and heavy freight vehicles. This applies to both rural and urban environments.

The equation for calculating externalities costs for passenger and bus movements is Equation 45.

*Equation 45: Externality cost*

$$Externality_i = UnitCost_{exty} \times VKT$$

Where:

- $Externality_i$  = externality cost per year per vehicle type (\$)
- $UnitCost_{exty}$  = externality unit cost per vehicle type and environment (c/km)
- VKT = vehicle kilometres travelled (AADT × SecLength × 365.25)

The unit externality costs are derived for both rural and urban environments for both passenger cars and buses. The unit costs are provided by Austroads in 2007 values as shown by Table 28.

*Table 28: Externality unit costs for passenger vehicles and buses (c/vkt)*

Vehicle/units	Urban		Rural	
	Passengers cars	Buses	Passengers cars	Buses
Air pollution	2.54 (2.48–2.60)	28.61 (20.24–31.82)	0.03 (0.02–0.03)	0.00 (0.00–0.32)
Greenhouse	2.00 (1.77–2.24)	11.79 (n/a)	2.00 (1.77–2.24)	11.79 (n/a)
Noise	0.82 (0.59–1.06)	2.00 (1.18–2.83)	0.00 (0.00)	0.00 (0.00)
Water	0.38 (0.37–0.39)	4.29 (3.04–4.77)	0.04 (0.04–0.04)	0.04 (0.03–0.05)
Nature and landscape	0.05 (0.05–0.17)	0.13 (0.13–0.6)	0.47 (0.47–1.65)	1.3 (1.3–6.01)
Urban separation	0.59 (0.35–0.82)	1.89 (1.18–2.6)	0.00 (0.00)	0.00 (0.00)
Upstream and downstream costs	3.42 (2.95–3.89)	17.68 (14.14–21.21)	3.42 (2.95–3.89)	17.68 (14.14–21.21)

Source: Austroads (2008) pages 25–29.

Note: Austroads provides unit cost ranges (in brackets). The non-bracketed values are an average of the supplied range.

*Example: Air pollution*

The externality cost for 100 passenger cars over a 5 km section of urban highway is:

$$\text{Externality}_i = \text{UnitCost}_{\text{ext}_y} \times 182,625$$

Air pollution externality costs are therefore given by:

$$\text{Air Pollution}_i = 2.54 \times 182,625$$

$$\text{Air Pollution}_i = 463,867.5 \text{ cents}$$

$$\text{Air Pollution}_i = \$4638.68 \text{ p.a.}$$

The air pollution cost to the environment from 100 cars travelling 5 km is \$4638 per annum.

The unit externality costs for light and heavy freight vehicles in both rural and urban environments are shown by Table 29.

Table 29: Externality unit costs for freight vehicles (\$ per 1000 tonne-km)

Vehicle/units	Urban		Rural	
	Light vehicles	Heavy vehicles	Light vehicles	Heavy vehicles
Air pollution range	158.93 (117.85–261.60)	21.19 (10.28–25.93)	0.00 (0.00)	0.21 (0.11–0.26)
Greenhouse range	49.50 (45.96–51.85)	4.71 (2.36–8.25)	49.50 (45.96–51.85)	4.71 (2.36–8.25)
Noise ranges	27.10 (18.86–37.71)	3.54 (2.36–4.71)	0.0 (0.00)	0.35 (0.24–0.49)
Water	23.84 (17.68–39.20)	3.18 (1.06–3.89)	0.24 (0.18–0.42)	1.27 (0.64–1.56)
Nature and landscape	17.68 (17.68–34.18)	0.35 (0.35–0.71)	0.18 (0.18–0.34)	3.54 (3.54–7.07)
Urban separation	25.93 (15.32–36.53)	2.36 (1.18–3.54)	0.00 (0.00)	0.00 (0.00)
Upstream and downstream costs	164.99 (117.85–212.13)	18.86 (16.5–21.21)	164.99 (117.85–212.13)	18.86 (16.5–21.21)

Source: Austroads (2008) pages 25–29.

To calculate the externality costs for freight vehicles, the unit externality costs per VKT are calculated using the gross combination mass (GCM) as detailed by Table 30.

Table 30: Gross combination mass (Queensland freight vehicles)

Vehicle type	Maximal length (m)	GCM (t)	Weight of freight (t)
Semi-trailer	19.00	42.50	36.5
Quad axle semi-trailer	19.00	46.50	40.5
B-double	26.00	62.50	46.5
Road train 1	36.50	79.00	73.0
B-triple	36.50	82.50	76.5
AB-triple	36.50	99.00	93.0
Road train 2	53.50	115.50	109.5
AAB-quad	53.50	142.50	136.5
BAB-quad	53.50	119.00	113
ABB-quad	53.50	119.00	113

Source: TMR.

The unit externality costs per VKT per vehicle are calculated as shown by Equation 46.

Equation 46: Heavy vehicle externality costs per VKT

$$UnitCost_{exty} = \frac{ExternalityCost_{per1000tkm} \times WeightofFreight(VT)}{10}$$

Where:

- $UnitCost_{exty}$  = externality unit cost per vehicle type and environment (c/km)
- $WeightofFreight(VT)$  = GCM – weight of prime mover

The unit externality costs per VKT for freight vehicles are given by Table 31.

Table 31: Externality unit costs for CBA6 heavy vehicles (c/VKT)

Vehicle/units	Urban				Rural			
	Articulated	B-double	Road train 1	Road train 2	Articulated	B-double	Road train 1	Road train 2
Air pollution	77.34	119.72	154.69	232.03	0.77	1.19	1.53	2.30
Greenhouse	17.19	26.61	34.38	51.57	17.19	26.61	34.38	51.57
Noise	12.92	20.00	25.84	38.76	1.28	1.98	2.56	3.83
Water	11.61	17.97	23.21	34.82	4.64	7.18	9.27	13.91
Nature and landscape	1.28	1.978	2.56	3.83	12.92	20.00	25.84	38.76
Urban separation	8.61	13.33	17.23	25.84	0	0	0	0
Upstream and downstream	68.84	106.56	137.68	206.52	68.84	106.56	137.68	206.52

Equation 47: Freight externality cost

$$FreightExternality_i = \frac{UnitCost_{Fexty} \times VKT_i}{100}$$

Where:

- $\text{FreightExternality}_i$  = Freight externality cost per year per vehicle type (\$)
- $\text{VKT}_i = \text{AADT}_i \times \text{section length} \times 365.25$

*Example: Freight externality cost*

The air pollution externality cost for 100 B-doubles over a 5 km section of urban highway per year is:

$$\text{VKT}_i = 100 \times 5 \times 365.25 = 182\,625$$

$$\text{AirPollutionExternalityCost} = \frac{119.72 \times 182,625}{100} = 218,639$$

The air pollution cost to the environment from 100 B-doubles travelling 5 km is \$218 639 per annum.

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# 4

## 8 Advanced projects

This section provides the methodologies and algorithms contained in CBA6 for the advanced modules. This section builds on the previous explanations of road user costs such as VOC, TTC and accident costs and applies those calculations to advanced projects. It outlines the methodologies applied to derive the following benefits/costs:

- flooding/diversions (diversions with a road closure)
- road closures (road closure with no diversion)
- generated traffic
- livestock damage
- intersections
- overtaking lanes.

All examples in this chapter are consecutive quantifications of a single year's user cost for the B-double vehicle type.

## 8.1 Road closure with diverting route

Flood immunity projects require a detailed understanding of both the road network and road user behaviour. As in Section 5.4.5 of the *User Guide*, road user responses to flooding can vary depending on the frequency, severity and extent of flooding. Flood warning times and the availability of alternative routes will also affect the decisions made by motorists. The following three options exist for motorists affected by flooded roads:

- Wait – remain at the flood site for waters to subside.
- Divert – use an alternative route around the flood affected area.
- Do not travel – choose not to travel at all.

### *Example: Flooded road*

In this example for a flooded road, the following assumptions apply:

- 10% – wait at the flooding site (wait for the flood to subside).
- 20% – divert to another route.
- 70% – choose not to travel during the flooding event at all.

Note: Proportions of road user behaviour must equal 100%.

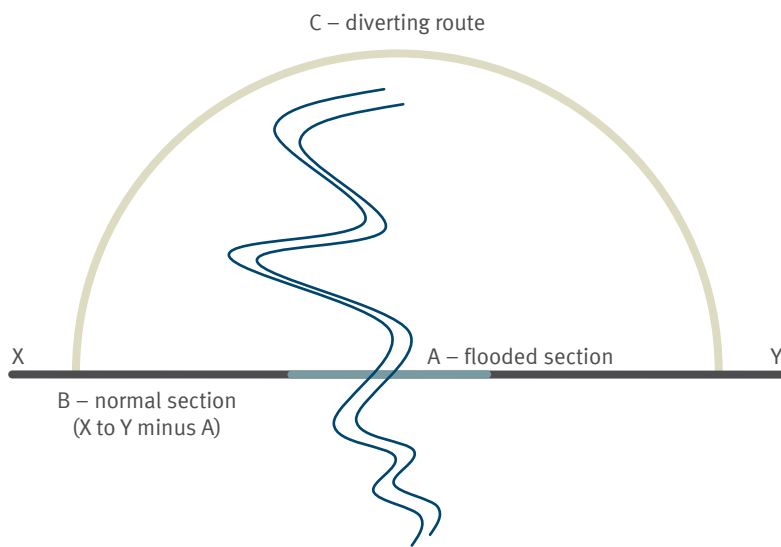
For all road closure projects CBA6 requires road closure information associated with local flooding and data on the AATOC and the ADC for the base and project cases.

Note: For further details on the costs of not travelling see Section 2.4.1.3 of the *Theoretical Guide*. CBA6 does not calculate road user costs for existing traffic.

Figure 3 illustrates the relevant sections of a flooding diversion which are identified as:

- Section A is the flood affected section, which is to be upgraded.
- Section B is the normal full length of the road, and is assumed to have the same road configuration as section A in the base case (prior to the upgrade). The length of B is the distance between X and Y minus the length of A.
- Section C is the diverting route, which can be substantially longer than section B and should be measured as the length along the diversion route between X and Y.

Figure 3: Flooding closure



### 8.1.1 Flooding data

The AATOC and ADC values are used in CBA6 to determine the waiting time during a flood event. These calculations are then used to estimate road user costs associated with the flood event. An example of flood data is shown by Table 32, and formulae for AATOC are given by Equation 48.

Table 32: Example base case flood data

Base case flood data																				
Years	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Number of floods	1	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0	1	0
Total time closed (hours)	60	0	0	0	0	0	0	68	0	0	48	0	0	24	0	0	0	0	80	0

#### 8.1.1.1 Average annual time of closure

Equation 48: Average annual time of closure

$$AATOC = \frac{(\sum \text{HoursClosed}_i)}{\text{Years}_i}$$

Where:

- AATOC = average annual time of closure
- HoursClosed<sub>i</sub> = total hours closed per flooding event
- Years<sub>i</sub> = number of years of flood data evaluated

The AATOC is the average number of hours a road is closed per year. The AATOC calculation is used throughout CBA6's flooding diversion module to estimate the proportion of the year that the given road is closed to traffic. It is important to note that averages are based on the range of time series flood data used. An appropriate number of observations should be obtained in the sample to represent accurate closure averages.

*Example: Average annual time of closure*

The average annual time of closure is calculated as follows:

$$AATOC = \frac{280}{20}$$

$$AATOC = 14$$

Using the data in Table 32, the road has been closed due to flooding for 280 hours over the last 20 years, which equates to an annual average closure time of 14 hours per year.

### 8.1.1.2 Average duration of closure

The ADC represents the average duration of each road closure per flood and is used in CBA6 to calculate costs incurred by the road users who opted to wait. The ADC calculation is given by Equation 49.

*Equation 49: Average duration of closure*

The average annual time of closure is calculated as follows:

$$ADC = \frac{(\sum \text{Hours Closed}_i)}{(\sum \text{NoFloods}_i)}$$

Where:

- ADC = average duration of closure
- NoFloods<sub>i</sub> = total number of floods over evaluation period

*Example: Average duration of closure*

The ADC is calculated as:

$$ADC = \frac{280}{5}$$

$$ADC = 56$$

Based on the data in Table 32, the road is closed for an average of 56 hours per flooding event. This derivation of AATOC and ADC is used by CBA6 to calculate road user costs based on the average number of days of the year that road users are affected by a flooding event.

## 8.1.2 CBA6 road user cost methodology

The CBA6 road user cost methodology is founded on the average period of closure during a flooding event and the traffic behaviour during this period. Road users have three choices when confronted with a flood event. The consequence and calculated costs of these choices are described by Table 33.



Table 33: Flood/diversion road user costs calculation

Section	During flood	No flood
A	Waiting costs calculated for % waiting	Road user costs calculated as normal
B	Road user costs forgone for % diverting and % no travel	No road user costs calculated (net zero)
C	Road user costs for % diverting only	No road user costs calculated

For the flood affected section (A), road user costs are calculated during the periods where there is no flood event (% of year). During a flood event, some road users will divert and some will choose not to travel. Waiting costs are calculated for those vehicles that choose to wait at the flood affected site.

For the improved route (B) and diversion route (C), road user costs are only calculated during periods of a flood event as the road user costs are assumed not to change from the base case to the project case when there is no flood event.

During a flood event, user costs are calculated for the improved route, as it is assumed to represent user costs forgone as road users divert. For the diversion route during a flood event, road user costs are calculated based on the percentage of vehicles which choose to divert (% AADT).<sup>1</sup>

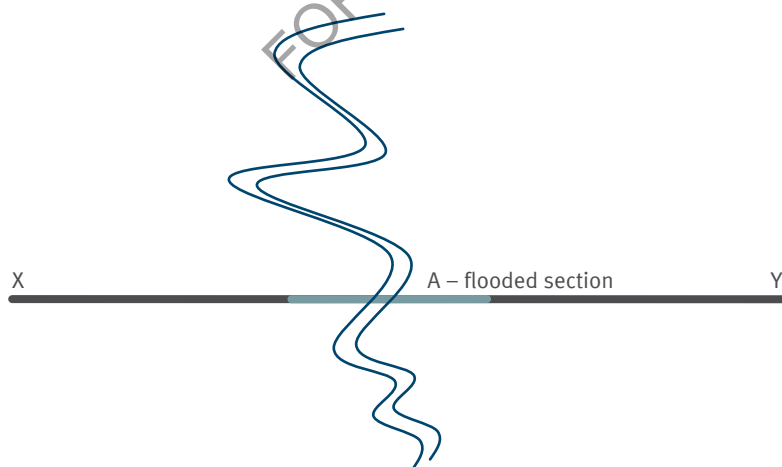
This methodology is highlighted in detailed road user cost algorithms.

- 8.1.3 Section A - project area
- 8.1.4 Section B - improved route
- 8.1.5 Section C - diversion route

### 8.1.3 Section A – project area

Section A refers to the flood prone section requiring the upgrade, see Figure 4. During periods when there are no flooding events, road users will not incur any additional road user costs by travelling through the section. During a flood event, the waiting costs associated with those vehicles that choose to wait at the flood site are calculated in CBA6.

Figure 4: Project area



<sup>1</sup> For mathematical proof of improved route methodology, see Appendix C.

### 8.1.3.1 Vehicle operating costs – Section A

VOC for Section A are shown by Equation 50. This equation shows that for the base and project cases VOCs are calculated for vehicles that travel on Section A for the proportion of the year that the road is open.

*Equation 50: Vehicle operating costs – Section A*

$$TOTVOC_A = SecLength_{BC/PC} \times \left( 365.25 - \left( \frac{AATOC}{24} \times \%D \right) \right) \times \sum_i \left( AADT_i \times \frac{VOC_i}{100} \right)$$

Where:

- $SecLength_{BC/PV}$  = section length as given in the base and project case
- $\%D$  = percentage of vehicles diverting during closure (%)
- $VOC_i$  = vehicle operating unit cost

Note: When  $\%D$  is equal to 0, no vehicles divert and VOC is calculated as per equations outlined in Section 4.

*Example: Vehicle operating costs – Section A*

Assume that there are 100 B-doubles travelling along a 5 km stretch of highway. The traffic behaviour during a flood event is anticipated to be 50% diverting, 30% waiting and 20% choosing not to travel at all. VOCs are assumed to be 255.42 c/km. It is also assumed that the length for the upgraded Section A is 5 km, the improved route is 10 km and the diverting route is 50 km. Other road characteristics are representative of examples illustrated in Sections 2 to 4. VOC are given below:

$$TOTVOC = 5 \times \left( 365.25 - \left( \frac{14}{24} \times 0.50 \right) \right) \times \sum_i \left( 100 \times \frac{255.42}{100} \right)$$

$$TOTVOC = \$ 466,088.29$$

The total VOC incurred over the year when flooding occurs is \$466 088.29.

### 8.1.3.2 Travel time cost – Section A

The TTC for Section A is given by Equation 51. This equation shows the base case and project case TTC.

*Equation 51: Travel time cost – Section A*

$$Total\ TTC_A = TripTime_{BC/PC} \times \left( 365.25 - \left( \frac{AATOC}{24} \times \%D \right) \right) \times \sum_i \left( AADT_i \times VTVEHR(VT) \right)$$

*Example: Travel time cost – Section A*

Using the data from the previous example, trip time and VTVEHR from Table 23, the total TTC for Section A is equal to:

$$Total\ TTC = 0.07753 \times \left( 365.25 - \left( \frac{14}{24} \times 0.5 \right) \right) \times \sum_i \left( 100 \times 48.40 \right)$$

$$Total\ TTC = 0.07753 \times 364.96 \times 484.0$$

$$Total\ TTC = \$13,694.95$$

The total TTC incurred over the year as a result of the flood is \$13 694.95.

### 8.1.3.3 Waiting costs – Section A

Road users who choose to wait at the flood affected site and continue their journey once the flood subsides, incur a waiting cost representative of the value of their personal and business time. The time spent waiting for the road to reopen is valued based on the number of vehicles which choose to wait at the flood affected site and the duration of the flooding event per year. The waiting time calculation is shown by Equation 52.

*Equation 52: Waiting time – Section A*

$$\text{Waiting Time} = \frac{1}{2} \left( AATOC - \frac{AATOC}{ADC} \times \left( \text{Trunc} \left( \frac{ADC}{24} \right) \times 12 \right) \right)$$

Where:

- Trunc = truncates a number to an integer by removing the fractional part of the number

The  $\frac{1}{2}$  shown by the waiting time equation represents an even distribution of vehicles while the truncation assumes a smaller proportion of vehicles will wait the entire length of the closure once the road has been closed for more than 24 hours. The waiting time is given in hours per year which is then used to calculate the costs associated with those vehicles which choose to wait.

*Example: Waiting time – Section A*

Waiting cost is based on the total waiting time of the closure. The waiting time is calculated as follows:

$$\text{Waiting Time} = \frac{1}{2} \times \left( 14 - \frac{14}{56} \times \left( \text{Trunc} \left( \frac{14}{24} \right) \times 12 \right) \right)$$

$$\text{Waiting Time} = 7 \text{ hrs}$$

*Equation 53: Waiting costs – Section A*

$$CW = \text{WaitingTime} \times \frac{ADC}{24} \times AADT(VT) \times \%VehWaiting \times VTVEHR(VT)$$

Where:

- CW = costs of waiting (\$)
- %VehWaiting = the proportion of vehicles waiting per vehicle type (%)

*Example: Waiting costs – Section A*

Waiting costs are then calculated as follows:

$$CW = 7 \times \frac{58}{24} \times 100 \times 30\% \times 48.40$$

$$CW = \$23,716$$

### 8.1.3.4 Crash costs

The crash costs for Section A are shown by Equation 54.

*Equation 54: Crash costs – Section A*

$$TOTACC_A = SecLength \times \left( 365.25 - \left( \frac{AATOC}{24} \times \%D \right) \right) \times \sum_i \left( \frac{AADT_i}{1,000,000} \right) \times A_{TR} \times AACCR_T$$

Where:

- $A_{TR}$  = total crash rate (Accidents/MVKT)
- $AACCR_T$  = average crash cost for road type (\$)

*Example: Crash costs – Section A*

Total crash costs for Section A are calculated as follows:

$$TOTACC_A = 5 \times \left( 365.25 - \left( \frac{14}{24} \times 0.5 \right) \right) \times \sum_i \left( \frac{100}{1,000,000} \right) \times 0.325704225 \times 229,145$$

$$TOTACC_A = \$ 13,619.06$$

#### 8.1.4 Section B – improved route

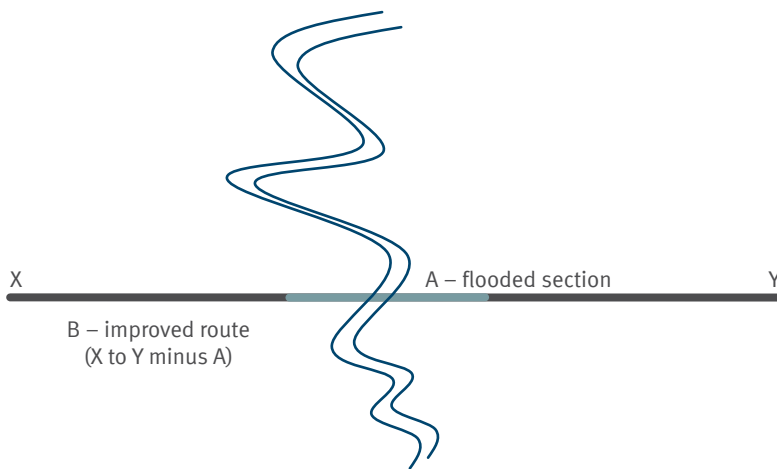
The improved route is assumed to be the section of road which vehicles are able to traverse during periods when the road is not closed. This route spans from the origin of the diversion route to the end of the diversion route (where the diverting traffic rejoins) minus the flooded section, see Figure 5. The assumption is made that under normal circumstances, road user costs for Section B are the same in the base and project cases and thus, the net difference would be 0.

The difference in costs that occur on the improved route when there is a flood due to road users not travelling or diverting is calculated. Based on this assumption the road user costs calculated are negative, i.e. road user costs not incurred.

For the mathematical proof of improved route methodology, see Appendix C – Mathematical proof of improved route calculation.

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Figure 5: Improved route



#### 8.1.4.1 Vehicle operating costs – Section B

VOC for Section B are shown by Equation 55.

Equation 55: Vehicle operating costs – Section B

$$TOTVOC_B = SecLength_{IR} \times \left( - \left( \frac{AATOC}{24} \times \%D \right) \right) \times \sum_i \left( AADT_i \times \frac{VOC_i}{100} \right)$$

Example: Vehicle operating costs – Section B

Calculation of VOC for the improved route is:

$$TOTVOC_B = 10 \times \left( - \left( \frac{14}{24} \times 0.5 \right) \right) \times \sum_i \left( 100 \times \frac{255.42}{100} \right)$$

$$TOTVOC_B = -\$744.98$$

#### 8.1.4.2 Travel time costs – Section B

TTC for Section B are shown by Equation 56.

Equation 56: Travel time costs – Section B

$$Total\ TTC_B = TripTime_{IR} \times \left( - \left( \frac{AATOC}{24} \times \%D \right) \right) \times \sum_i \left( AADT_i \times VTVEHR(VT) \right)$$

Example: Travel time costs – Section B

Calculation of TTC for the improved route is:

$$Total\ TTC_B = 0.155 \times \left( - \left( \frac{14}{24} \times 0.5 \right) \right) \times \sum_i \left( 100 \times 48.40 \right)$$

$$Total\ TTC_B = -\$218.81$$

### 8.1.4.3 Crash costs – Section B

Crash costs for section B are shown by Equation 57.

*Equation 57: Section B crash costs*

$$TOTACC_B = SecLength \times \left( - \left( \frac{AATOC}{24} \times \%D \right) \right) \times \sum_i \left( \frac{AADT_i}{1,000,000} \right) \times A_{TR} \times AACC_{RT}$$

*Example: Crash costs – Section B*

Total crash costs for Section B are:

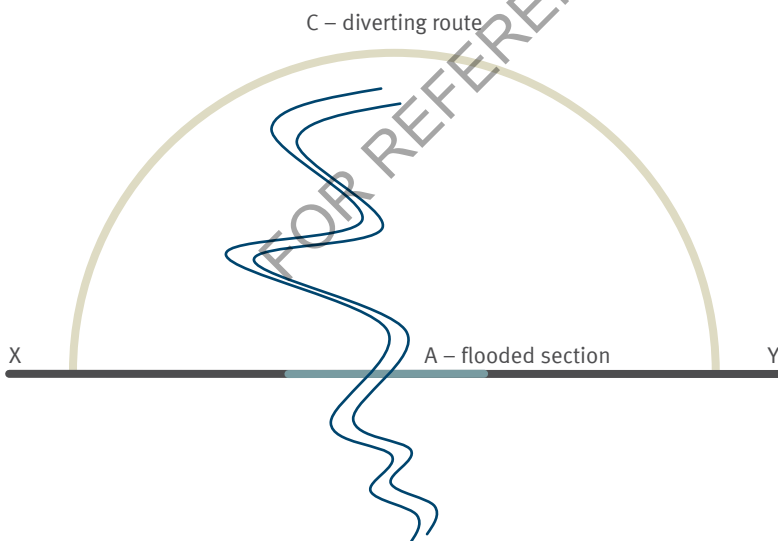
$$TOTACC_B = 10 \times \left( - \left( \frac{14}{24} \times 0.5 \right) \right) \times \sum_i \left( \frac{100}{1,000,000} \right) \times 0.325704225 \times 229,145$$

$$TOTACC_B = -\$21.77$$

### 8.1.5 Section C – diversion route

The diverting route road user costs are only calculated during a flooding event. When a road closure occurs at Section A, some vehicles that would normally traverse the flood affected site, will now divert to an alternative route to complete their journey. The traffic diverting from Section A will join the existing traffic travelling along the diverting route.<sup>2</sup>

*Figure 6: Diversion route*



#### 8.1.5.1 AADT – Section C

AADT on the diverting route during closure periods is determined by Equation 58. This equation incorporates the proportion of vehicles that choose to divert and the number of existing road users on the diversion route.

<sup>2</sup> Previous versions of the tool assumed that the road user costs of existing road users would be included in the diversion calculation during a flooding event. Old versions however, did not fully capture the road user costs incurred by existing traffic in the project case. CBA6 now omits existing traffic on the diverting route.

*Equation 58: AADT – Section C*

$$\%BD_{DR} = \frac{\%BD_D \times AADT_D + \%BD_E \times AADT_E}{AADT_D + AADT_E}$$

Where:

- $\%BD_{DR}$  = percentage breakdown of traffic on the diverting route
- $\%BD_D$  = percentage breakdown of diverting traffic
- $\%BD_E$  = percentage breakdown of existing traffic on the diversion route
- $AADT_D$  = traffic volume of diverting traffic
- $AADT_E$  = traffic volume of existing traffic

*Example: AADT – Section C*

If the diverting route consists of 5000 diverting vehicles and 2000 existing vehicles, and if 10% of diverting vehicles are B-doubles while 17% of existing vehicles are B-doubles, the percentage breakdown of B-doubles along the diverting route during a closure is:

$$\%BD_{DR} = \frac{17\% \times 2000 + 10\% \times 5000}{2000 + 5000} = 12\%$$

### 8.1.5.2 Traffic growth rate

Growth rate of AADT on the diversion route is made up of the increase in traffic on the normal route and the diversion route. The growth rate formula is shown by Equation 59.

*Equation 59: AADT growth – Section C*

$$G_{DR} = \frac{G_D \times AADT_D + G_E \times AADT_E}{AADT_D + AADT_E}$$

Where:

- $G_{DR}$  = growth rate on diverting route (%)
- $G_D$  = growth rate of diverting traffic (%)
- $G_E$  = growth rate of existing traffic (%)

*Example: AADT growth – Section C*

If the growth rate of the diverting traffic is 5.1%, while the growth rate of the existing traffic is 3%, the growth rate of the traffic along the diverting route is:

$$G_{DR} = \frac{5.1\% \times 2000 + 3\% \times 5000}{2000 + 5000} = 3.6\%$$

### 8.1.5.3 Vehicle operating costs – Section C

VOC for Section C are shown by Equation 60.

Note: The traffic component is incorporated in the diversion route.

*Equation 60: Vehicle operating costs – Section C*

$$TOTVOC_C = SecLength_{DR} \times \frac{AATOC}{24} \times \sum_i \left( (AADT_{di}) \times \frac{VOC_i}{100} \right)$$

Where:

- $AADT_{di}$  = average annual daily traffic of diverting traffic

*Example: Vehicle operating costs – Section C*

For the B-double example on a 50 km diverting route with similar characteristics of the upgraded section where there is no existing traffic.

$$TOTVOC_C = 50 \times \frac{14}{24} \times \sum_i \left( 50 \times \frac{255.42}{100} \right)$$

$$TOTVOC_C = \$3,724.875$$

### 8.1.5.4 Travel time cost – Section C

TTC for Section C are shown by Equation 61.

Note: The traffic component is incorporated in the diversion route TTC.

*Equation 61: Travel time costs – Section C*

$$Total\ TTC_C = TripTime_{DR} \times \frac{AATOC}{24} \times \sum_i (AADT_{di} \times VTVEHR(VT))$$

*Example: Travel time costs – Section C*

TTC for the B-double example is calculated as follows:

$$Total\ TTC_C = 0.77531 \times \frac{14}{24} \times \sum_i 50 \times 48.40$$

$$Total\ TTC_C = \$1,094.48$$

Note: Trip time in this example is based on the B-double travelling at 80 km/h for the 50 km diversion route.

### 8.1.5.5 Crash costs – Section C

Crash costs for Section C are shown by Equation 62.

Note: The traffic component is incorporated in the diversion route.



Equation 62: Crash costs – Section C

$$TOTACC_C = SecLength \times \frac{AATOC}{24} \times \sum_i \frac{AADT_{di}}{1,000,000} \times A_{TR} \times AACCR_T$$

Example: Crash costs – Section C

Crash costs for the diverting route are:

$$TOTACC_C = 50 \times \frac{14}{24} \times \sum_i \left( \frac{50}{1,000,000} \right) \times 0.325704225 \times 229,145$$

$$TOTACC_C = \$108.84$$

### 8.1.6 Total road user cost – flooding diversion

Total road user costs and benefits in a flooding diversion are calculated by Equation 63.

Equation 63: Total road user costs

$$TotalRUC_{BC/PC} = RUC_A + Wait_A + RUC_B + RUC_C$$

Where:

- Road user costs = total road user costs for the relevant section (VOC + TTC + ACC)
- Wait<sub>A</sub> = waiting costs (Section A)

Example: Total road user costs

The annual net cost from the examples above is as follows:

$$Total Cost_{BC} = (466,088.29 + 13,694.95 + 13,619.06) + 23,716 + (-744.98 - 218.81 - 21.77) \\ + (3724.88 + 1094.48 + 108.84)$$

$$Total Cost_{BC} = 493,402.30 + 23,716 - 985.56 + 4928.20$$

$$Total Cost_{BC} = \$521,060.94$$

The net benefits of a flooding/diversion are derived from road user costs calculated for all years in the evaluation for both base and project cases. The total road user costs are also discounted, see Section 9.1. Benefits are the total discounted base case costs minus the project case equivalents.

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## 8.2 Road closures

With the exception of the diversion and improved route calculations, the road closure module in CBA6 follows the same methodology as the flooding diversion module. In road closure scenarios, such as rock falls and flooding, road users are not provided with a viable alternate route and have only two options:

- Wait at the closure site.
- Choose not to travel at all.

Based on the percentage of road users who choose to wait at the project site, CBA6 calculates the average duration of the road closure per year and waiting costs associated with the closure. Road user costs defined in Section 4 are calculated during periods where the road is not closed. Similar to the flooding diversion, those road users who choose not to travel at all during the road closure do not incur any additional road user costs for the duration of the closure.

Note: For further details on the costs of not travelling see Section 2.4.1.3 of the *Theoretical Guide*.

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## 8.3 Intersections

The intersection module is dependent on SIDRA outputs, see Table 34. Consequently, the accuracy of the CBA6 results is dependent on the accuracy of the SIDRA modelling. Information is required for two or more years of the evaluation period, for both base and project cases. This requires at least four runs of the SIDRA intersection analysis tool depending on the number of time periods to be modelled. For this reason, generally only the peak periods are evaluated. For a more detailed discussion on the intersection module, see Section 5.5 of the *User Guide*. Data from alternative modelling tools could be used if converted to SIDRA output format.

Table 34: CBA6 intersection inputs

Period description	Period duration (hours)	Flow (veh/hour)	Average delay (seconds)	Fuel consumption (l/hour)
Morning peak	1	1000	20	100
Afternoon peak	1	2000	30	75
Non-peak	10	0	0	0
Night	12	0	0	0
Weekend day	12	0	0	0
Weekend night	12	0	0	0

One year is assumed to consist of 260.9 weekdays and 104.4 weekend days (i.e.  $365.25 \times 5/7$  and  $365.25 \times 2/7$ ). Hence, there are 260.9 morning peak periods and 104.4 weekend periods in a year.

Note: The flow rate (veh/hour) is representative of all vehicles in the fleet.

### 8.3.1 Delay cost calculation

The average delay in seconds is converted into hours per year per vehicle type. This calculation is shown by Equation 64.

Equation 64: Annual delay (hours)

$$Delay(VT) = \frac{averagedelay}{3600} \times flow(VT) \times duration(period) \times periods\ per\ year$$

Example: Annual delay (hours)

Using inputs from Table 34, the average delay in hours in the morning peak for a B-double at a rural intersection is calculated by the following:

$$Delay(B - Double) = \frac{20}{3600} \times 35 \times 1 \times 260.9 = 50.73\ hrs$$

The average delay of 20 seconds in the morning peak impedes the B-double fleet by 50.73 hours each year.

Note: It is assumed that there are 3.5% B-doubles out of the total vehicle flow deriving an am peak flow of 35 B-doubles.

Vehicle delay time is multiplied by the unit cost of time. The annual delay cost per vehicle type is shown by Equation 65.

Equation 65: Annual delay cost

$$Annual\ Delay\ Cost(VT) = Delay(VT) \times VTVEHR(VT)$$

Where:

- Time cost VTVEHR(VT) = TTC per vehicle (\$)

### Example: Annual delay cost

Following the previous example, the annual delay cost is calculated as follows:

$$\text{Annual Delay Cost}(B - \text{Double}) = 50.73\text{hrs} \times 48.40/\text{h}$$

$$\text{Annual Delay Cost}(B - \text{Double}) = \$2455.38 \text{ p. a}$$

Delays in the morning peak cost the B-double fleet \$2455 each year.

## 8.3.2 Fuel cost calculation

In the intersection module, only VOC incurred by road users are fuel consumption costs. The basic fuel consumption is calculated by Equation 66.

### Equation 66: Basic fuel consumption

$$BFC(VT) = \left( \text{Square}(VT) \times OS^2 + \frac{\text{Reciprocal}(VT)}{OS} + \text{Constant}(VT) \right) \times FCAVF$$

Where:

- BFC(VT) = basic fuel consumption per vehicle type (L/1000 km)
- Square(VT) = model parameter
- OS(VT) = operating speed calculation for each vehicle type (30 km/h)
- Reciprocal(VT) = model parameter
- Constant(VT) = model parameter

Note: The intersection module operating speed is assumed to equal 30 km/h.

The variables in the formula are sourced from Table 10, Section 4 and are reproduced in Table 35.

Table 35: Intersection BFC variables

Vehicle type	FCAVF	Constant	Reciprocal	Square	BFC
Cars – private	1.07	37.30	1 526.20	0.01	96.40
Cars – commercial	1.07	38.90	1 883.00	0.01	140.92
Non-Articulated	1.10	49.00	3 485.10	0.02	239.97
Buses	1.10	69.40	5 451.10	0.01	239.97
Articulated	1.10	118.60	9 621.10	0.02	445.52
B-double	1.10	172.70	14 720.40	0.02	745.56
Road train 1	1.10	223.60	17 201.80	0.01	891.34
Road train 2	1.10	312.10	26 646.90	0.02	1 335.21

Source: Austroads (2005) and TMR calculations.

### Example: Basic fuel consumption

Using the same B-double example at an operating speed of 30 km/h, the basic fuel consumption is calculated as follows:

$$BFC(B - Double) = 745.56 \text{ L}/1000\text{km}$$

The fuel proportion weighting for each vehicle type, based on the volume and BFC of each vehicle type, relative to the BFC of a private car is shown by Equation 67.

### Equation 67: Fuel proportion

$$\text{Fuel Proportion}(VT) = \frac{\text{Veh/hr}(VT) \times BFC(VT)}{\sum(\text{Veh/hr} \times BCF(VT))}$$

Where:

- Veh/hr(VT) = vehicles per hour for a specific vehicle type (Flow)
- BFC(VT) = basic fuel consumption for the target vehicle, see Table 35

### Example: Fuel proportion example

In the B-double example, the total fuel consumption for all vehicles is 164 052.6; this figure can be verified in Table 36. The fuel proportion is calculated as:

$$\text{Fuel Proportion}(B - Double) = \frac{35 \times 745.56}{164,052.60}$$

$$\text{Fuel Proportion}(B - Double) = 15.91\%$$

The fuel consumption for each vehicle type, using the total fuel consumption value output by SIDRA, is shown by Equation 68.

### Equation 68: Fuel consumption

$$\text{Fuel Consumption}(VT) = \text{fuelcons}(SIDRA) \times \text{Fuel Proportion}(VT)$$

Where:

- Fuelcons(SIDRA) = fuel consumption (L/hr) as per SIDRA output

### Example: Fuel consumption

Fuel consumption for a B-double is:

$$\text{Fuel Consumption}(B - Double) = 100 \times 15.91\%$$

$$\text{Fuel Consumption}(B - Double) = 15.91 \text{ L/hr}$$

Morning peak fleet fuel consumption of 100 litres per hour equates to 15.91 litres per hour for a B-double.

Annual fuel cost for each vehicle type, using the weighted average fuel price (fuelcf) is shown by Equation 69.

*Equation 69: Annual fuel cost*

$$AnnualFuelCost(VT) = FuelCons(VT) \times \frac{Fuelcf}{100} \times PeriodPerYear \times HrsPerPeriod$$

Where:

- AnnualFuelCost(VT) = annual fuel cost per vehicle type
- FuelCons (VT) = fuel consumption per vehicle type (L/hr)
- Fuelcf = weighted fuel cost per vehicle type

*Example: Annual fuel cost*

In the B-double example, the annual fuel cost is calculated, assuming the weighted fuel cost for a B-double equals 81.57 cents per litre:

$$AnnualFuelCost(B - Double) = 15.91 \times \frac{81.57}{100} \times 260.90 \times 1$$

$$AnnualFuelCost(B - Double) = \$3385.10 \text{ p. a}$$

Table 36 shows the complete calculation of fuel costs in the morning peak using the previous intersection calculations.

*Table 36: Intersection fuel cost example*

Vehicle type	Flow (veh/hr)	Morning peak fuel cost			Fuel consumption (l/hr)	Annual fuel cost (\$)
		BFC (l/1000km)	Flow fuel consumption	Fuel proportion (%)		
Cars – private	700.00	96.40	67 480.50	41.13	41.13	8 852.59
Cars – commercial	100.00	140.92	14 091.50	8.59	8.59	1 848.63
Non-Articulated	100.00	239.97	23 996.87	14.63	14.63	3 130.53
Buses	5.00	239.97	1 199.84	0.73	0.73	156.18
Articulated	50.00	445.52	22 275.92	13.58	13.58	2 892.99
B-double	35.00	745.56	26 094.53	15.91	15.91	3 385.10
Road train 1	10.00	891.34	8 913.45	5.43	5.43	1 156.29
Road train 2	-	1 335.21	-	0.00	0.00	0.00
Total	1 000.00	4 134.89	164 052.60	100.00	100.00	21 422.30

### 8.3.3 Accident cost calculation

Accident costs for intersection evaluations are manually entered by the system user on a yearly basis. The manual calculation of accident costs can be derived using the formulae provided in Section 6.

Note: Average intersection crash costs per million vehicles entering an inter (MVE) are provided in Appendix F as per Austroads (2001) AP-R/184.

*Example: Intersection accident*

The crash cost for 1000 vehicles using the intersection with an average accident cost of \$229 145 as per Section 6 is derived by the following:

$$CrashCost_{RT} = MVE \times A_{TR} \times AAcc_{RT}$$

$$CrashCost_{RT} = \frac{1000 \times 365.25 \times 1}{1,000,000} \times 0.25 \times \$229,145$$

$$CrashCost_{RT} = 0.36525 \times 0.25 \times 229,145$$

$$CrashCost_{RT} = \$20,924/\text{year}$$

In this example a project specific crash rate has been adopted based on the accident history of the intersection.

### 8.3.4 Benefit calculation

Calculation of benefits derived from an intersection evaluation using the outputs from SIDRA in CBA6 is shown by Equation 70.

*Equation 70: Total benefit*

$$TotalBenefit = (TotalBaseCosts) - (TotalProjectCosts)$$

Where:

- TotalBaseCosts = Base delay costs + base fuel costs + base accident costs
- Total project Costs = Project delay costs + project fuel costs + project accident costs

Calculations of benefits are completed for each year of the evaluation in both the base and project cases. Where SIDRA data is only provided in the first and last year of the evaluation, intermittent data sets are interpolated through Equation 71.

*Equation 71: Linear intersection interpolation*

$$Value_{YrZ} = Value_{YrX} + (YrZ - YrX) \times \left( \frac{Value_{YrY} - Value_{YrX}}{YrY - YrX} \right)$$

Where:

- Value<sub>YrZ</sub> = value of the interpolated variable in a year for which data has not been provided
- Value<sub>YrX</sub> = value of the first variable provided by the data
- Value<sub>YrY</sub> = value of the second variable provided by the data

Note: Data can be entered for each individual year, although this will first require multiple runs of SIDRA.

## 8.4 Overtaking lanes

Overtaking lane methodology takes into account recent research on accident reductions from the Austroads report AP-R184. Reduction in crashes depends on the type of overtaking lane constructed. The methodology applied to the calculation of the reduction of crashes is different than the methodology applied to the calculation of the reduction of crashes of a standard road evaluation.

### 8.4.1 Travel time costs and vehicle operating costs calculation

The capacity of the downstream section is assumed to increase by 20% because of the construction of the overtaking lane. Length of the downstream and upstream areas is assumed to be 5 km and 3 km respectively. For more information on the downstream and upstream areas, see Section 2.4.5 of the *Theoretical Guide*.

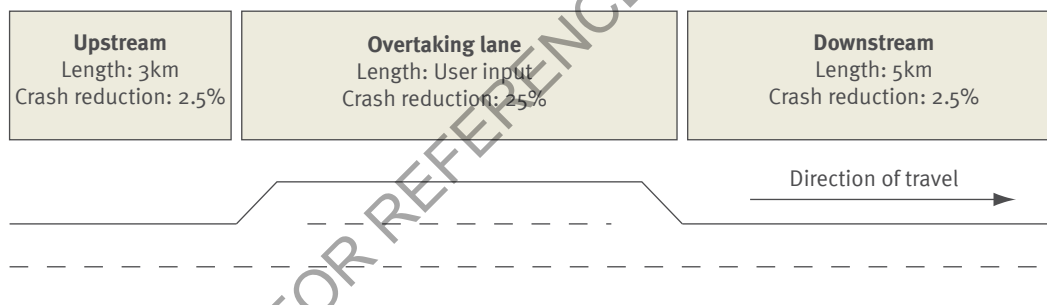
### 8.4.2 Crash costs

Provision of an overtaking lane will reduce the frequency of crashes for the road sections immediately before, during and after the overtaking lane location (Austroads 2001). Crash cost reduction for the three types of overtaking lanes is shown by Sections 8.4.2.1 to 8.4.2.3 of the *Theoretical Guide*.

#### 8.4.2.1 Single overtaking lane

The crash cost reduction for a single overtaking lane is illustrated by Figure 7.

Figure 7: Single overtaking lane



Calculations for crash reductions are specified in monetary terms for a single overtaking lane by Equation 72. Accidents are reduced by 25% in the section where the overtaking lane is constructed, 2.5% in the 3 km upstream section and 2.5% in the 5 km downstream area. These reductions are applied to Equations 72 to 74.

Equation 72: Single overtaking lane crash reduction

$$Reduction_{OTL_{Single}} = [(0.25 \times SecLength)A_R \times AADT \times 365.2 \times 10^{-6}] \times Av. Crash Cost$$

$$Reduction_{UP_{Single}} = [(0.025 \times 3)A_R \times AADT \times 365.25 \times 10^{-6}] \times Av. Crash Cost$$

$$Reduction_{DN_{Single}} = [(0.025 \times 5)A_R \times AADT \times 365.25 \times 10^{-6}] \times Av. Crash Cost$$

Where:

- $Reduction_{OTL_{Single}}$  = reduction in crashes for the overtaking section



- $ReductionUP_{Single}$  = reduction in crashes for the upstream section
- $ReductionDN_{Single}$  = reduction in crashes for the downstream section
- $A_R$  = base case crash rate for the relevant section (crashes per MVKT)
- $SecLength$  = length of the relevant section (km)

*Example: Single overtaking lane crash reduction*

The reduction in crashes for a 2 km overtaking lane on a highway with MRS of 12 and 1000 vehicles is calculated by:

$$ReductionOTL_{Single} = [(0.25 \times 2)0.281690141 \times 1000 \times 365.25 \times 10^{-6}] \times 229,145$$

$$ReductionOTL_{Single} = \$11,788.06$$

$$ReductionUP_{Single} = [(0.025 \times 3)0.281690141 \times 1000 \times 365.25 \times 10^{-6}] \times 229,145$$

$$ReductionUP_{Single} = \$1768.21$$

$$ReductionDN_{Single} = [(0.025 \times 5)0.281690141 \times 1000 \times 365.25 \times 10^{-6}] \times 229,145$$

$$ReductionDN_{Single} = \$2947.01$$

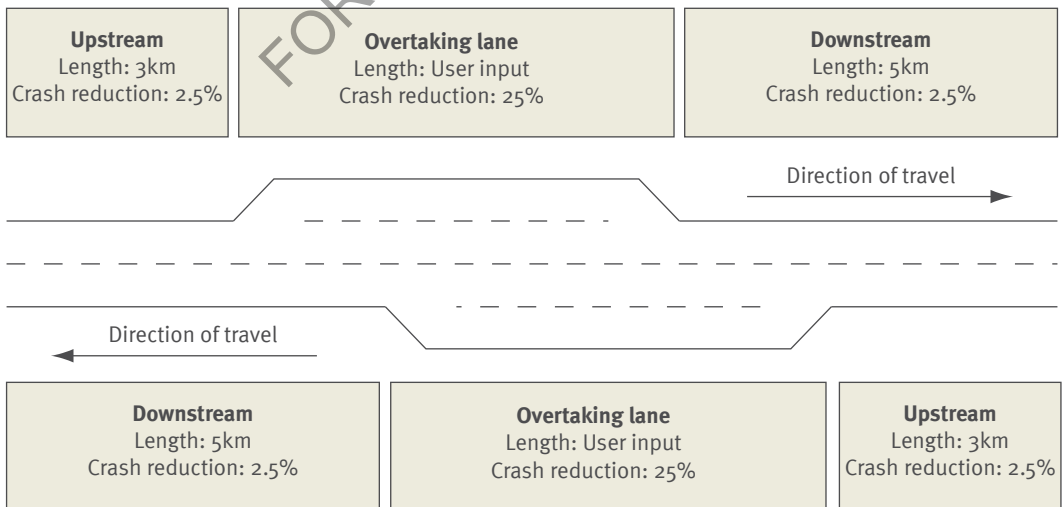
Crash cost reduction is the sum of the single, upstream and downstream overtaking lane sections. The total crash cost reduction as a result of the overtaking lane above is equal to \$16 503.28.

Note: The difference between the upstream and downstream benefits is a factor of the section length.

**8.4.2.2 Head-to-head overtaking lane**

The crash reduction of a head-to-head overtaking lane is illustrated by Figure 8.

*Figure 8: Head-to-head overtaking lane*



Equations for calculating the crash cost reduction for a head-to-head overtaking are shown by Equation 73.

*Equation 73: Head-to-head overtaking lane accident reduction*

$$ReductionOTL_{hth} = [0.25(2 \times SecLength - SS)A_R \times AADT \times 365.25 \times 10^{-6}] \times AvCrashCost$$

$$ReductionUP_{hth} = [(2 \times 0.025 \times 3)A_R \times AADT \times 365.25 \times 10^{-6}] \times AvCrashCost$$

$$ReductionDN_{hth} = [(2 \times 0.025 \times 5)A_R \times AADT \times 365.25 \times 10^{-6}] \times AvCrashCost$$

Where:

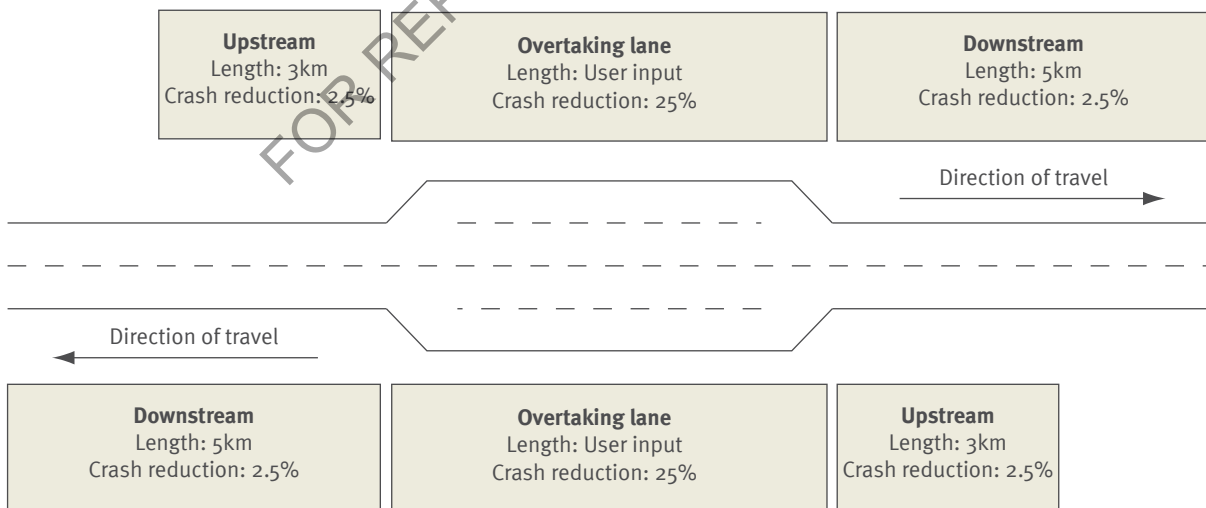
- ReductionOTL<sub>hth</sub> = reduction in crashes for the overtaking section
- ReductionUP<sub>hth</sub> = reduction in crashes for the upstream section
- ReductionDN<sub>hth</sub> = reduction in crashes for the downstream section
- A<sub>R</sub> = base case crash rate for the relevant section (crashes per MVKT)
- SecLength = length of the relevant section (km)
- SS = section length of the overtaking lane that runs side-by-side

Note: Unlike single overtaking lanes, accident reductions for head-to-head overtaking lanes are derived from two upstream and downstream areas.

**8.4.2.3 Side-by-side overtaking lane**

Equations for calculating the crash cost reduction for a side-by-side overtaking lane are shown by Equation 74. Figure 9 illustrates the crash reduction of a side-by-side overtaking lane.

*Figure 9: Side-by-side overtaking lane*



*Equation 74: Side-by-side overtaking lane accident reduction*

$$ReductionOTL_{sbs} = [(0.25 \times SecLength)A_R \times AADT \times 365.25 \times 10^{-6}] \times AvCrashCost$$

$$ReductionUP_{sbs} = [(2 \times 0.025 \times 3)A_R \times AADT \times 365.25 \times 10^{-6}] \times AvCrashCost$$

$$ReductionDN_{sbs} = [(2 \times 0.025 \times 3)A_R \times AADT \times 365.25 \times 10^{-6}] \times AvCrashCost$$

Where:

- ReductionOTL<sub>sbs</sub> = reduction in crashes for the overtaking section
- ReductionUP<sub>sbs</sub> = reduction in crashes for the upstream section
- ReductionDN<sub>sbs</sub> = reduction in crashes for the downstream section
- AR = base case crash rate for the relevant section (crashes per MVKT)
- SecLength = length of the relevant section (km)

Note: The side-by-side overtaking lane is not expected to provide the same amount of safety benefits when compared to the head-to-head overtaking lane. The side-by-side configuration is usually constructed over a shorter 'net' distance. For example, the head-to-head overtaking lane can be constructed as two separate overtaking lanes at 3 km each, which equates to 6 km in total, whereas two side-by-side overtaking lanes, 3 km each, only accounts for 3 km in total road section.

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## 8.5 Generated traffic

As discussed in Section 2.4.2 of the *Theoretical Guide*, generated traffic is the number of additional road users making trips in the project case. The benefits of generated traffic can be illustrated by the increase in consumer surplus in Figure 10.

Figure 10: Generated traffic

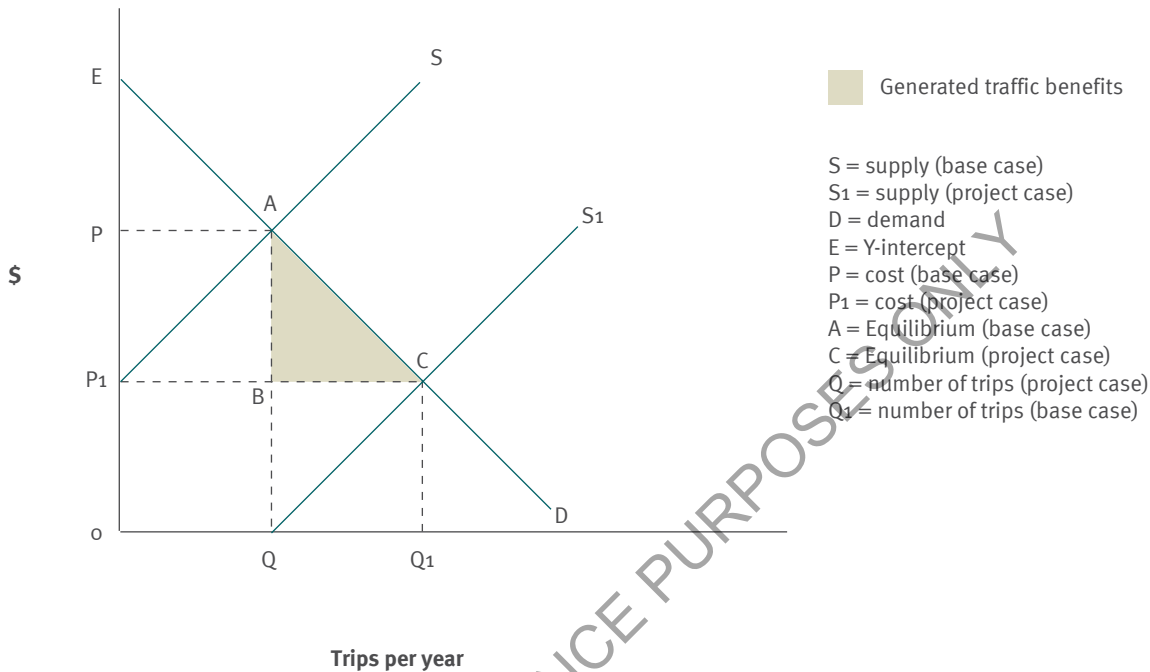


Figure 10 shows that when road user costs decline from  $p$  to  $p_1$ , the declining perceived cost per trip entices more trips to be made by transport and generates additional road users. The declined perceived cost per trip is a result of an improvement in the quality of the road. The benefit accruing to those generated road users is measured by the triangle, ACB. The generated traffic module in CBA6 measures the benefit represented by this triangle by applying 'the rule of half'.

Note: The theory of generated traffic benefits should not be applied to an evaluation with a capacity constraint issue.

The generated traffic benefit calculation is given by Equation 74. This equation applies the 'rule of half' to calculate the benefits of increased road use by incorporating the benefits of lower TTC and VOC.

Equation 75: Generated traffic

$$Benefits_{GENTRAF} = \frac{(((TTC_{BC} + VOC_{BC}) - (TTC_{PC} + VOC_{PC})) \times GenTraffic)}{2}$$

Where:

- $Benefits_{GENTRAF}$  = the total value of generated traffic benefits derived in CBA6 (\$)
- GenTraffic = the number of vehicles generated from a project (vehicles)
- $TTC_{BC}$  and  $VOC_{BC}$  = base case annual total road user cost per vehicle
- $TTC_{PC}$  and  $VOC_{PC}$  = project case annual total road user cost per vehicle

Note: Total road user costs (TTC and VOC) are calculated as follows:

$$RUC = \frac{Sec\ Length \times Unit\ RUC \times 365.25}{100}$$

*Example: Generated traffic*

Table 37 outlines a generated traffic example which shows that an upgrade of a 5 km section of road offers a significant reduction in travel cost which in turn is expected to generate 50 extra trips made by private vehicles. Using the data in Table 37 and Equation 75, the benefit from generated traffic is:

$$Benefit_{GENTRAF} = \frac{((253.85 + 279.42) - (228.25 + 255.68)) \times 50}{2}$$

$$Benefit_{GENTRAF} = \$1232.72\ p.a$$

The above calculations show that the economic benefit of an increase in the number of private vehicles is \$1233 where the benefit to existing road users is \$4930.

*Table 37: Generated traffic (private vehicle)*

Case	Section length (km)	TTC (c/km)	VOC (c/km)	TTC per vehicle (\$ p.a)	VOC per vehicle (\$ p.a)	AADT	Generated vehicles	Annual existing benefit	Annual generated benefit (\$)
Base	5	13.9	15.3	253.85	279.42	100	50	4 930.88	1 232.72
Project	5	12.5	14.0	228.28	255.68	150			

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## 8.6 Livestock damage

Damage to livestock occurs as a result of dust inhalation and jarring on unpaved or unsealed roads. Livestock damage benefits are calculated using default values from Table 38. This table shows that the default livestock benefit is based on the change in MRS between the base and project cases. For example, if the base case road has an MRS of 1 (unsealed natural surface) and the road is upgraded to an MRS of 3 (paved < 4.5 m), the benefit per kilometer for a B-double is \$0.605.

The largest livestock benefit accrues when an unsealed/formed road is upgraded to a sealed surface in the project case. The lowest benefits occur when a paved road is sealed.

Table 38: Damage to livestock benefits

Heavy vehicle type	Benefits (\$/km)		
	Unsealed/formed road to sealed road	Unsealed/formed road to gravel/paved road	Paved road to sealed road
	MRS 1, 2 to MRS 5+	MRS 1, 2 to MRS 3,4	MRS 3,4 to MRS 5+
Articulated	0.304	0.202	0.104
B-double	0.909	0.605	0.304
Road train 1	0.909	0.605	0.304
Road train 2	0.909	0.605	0.304

Source: TMR, see Appendix I – model road state.

The proportion of heavy vehicles carrying livestock requires specification in order for CBA6 to calculate the livestock damage benefits. Equation 76 can be used to determine the proportion of total vehicles carrying livestock.

Equation 76: Vehicles carrying livestock

$$\%Livestock(VT) = \frac{VT_{Livestock}}{VT_{Total}}$$

Example: Vehicles carrying livestock

The AADT along an unsealed paved road is 200 and there are approximately 20 B-doubles, with only five of the 20 B-doubles carrying livestock.

$$\%Livestock(B - Double) = \frac{5}{20} = 25\%$$

25% would be entered in the livestock column for B-doubles.

After the proportion of vehicles carrying livestock has been determined, the benefits that are attributable to these vehicles can be calculated using Equation 77. This shows the annual livestock damage benefit for those heavy vehicles carrying livestock based on the road upgrade benefit from Table 38.

Equation 77: Annual livestock benefits

$$Benefits_a = \sum_{VT} Benefit_{i(VT)} \times AADT(VT) \times Livestock_c \% (VT) \times 365.25 \times SecLength$$

*Example: Annual livestock benefits*

Table 39 illustrates the calculation of livestock benefits for a 10 km upgrade from an unsealed road with an MRS 4, to a sealed road with an MRS 7. By inputting the assumed data presented in Table 39 into Equation 77, the benefits per year by vehicle type can be calculated. The results of these calculations are shown in the ‘benefits/year’ column of Table 39.

Table 39 shows that a benefit of \$0.304 per kilometre per vehicle, for 35 B-double vehicles, travelling 10 km, on a road upgraded from an unsealed road with an MRS of 4 to a sealed road with an MRS of 7, is equivalent to a benefit of \$31 724.

*Table 39: Damage to livestock benefits example*

Vehicle type	Benefits (\$/km)	Section length (km)	Number of vehicles	Breakdown (%)	Number carrying livestock	Livestock (%)	Benefits/year (\$)
Cars – private	-	10	700	70.0	-	-	-
Cars – commercial	-	10	100	10.0	-	-	-
Non-Articulated	-	10	100	10.0	-	-	-
Buses	-	10	5	0.5	-	-	-
Articulated	0.104	10	50	5.0	20	40.0%	15 194.40
B-double	0.304	10	35	3.5	10	28.6%	31 724.57
Road train 1	0.304	10	10	1.0	2	20.0%	22 207.20
Road train 2	0.304	10	0	0.0	0	-	-
Total	-	10	1000	100	32	-	69 126.17

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## 8.7 Bypass

A bypass is a new road which provides an alternative route for traffic around a town or built-up area. In a bypass, the total costs of all individual links are compared with a proposed bypass. Evaluations of bypasses tend to be data intensive depending on the magnitude of the bypass. For an example of a bypass, see Section 5.7 of the *User Guide*.

In terms of methodology, CBA6 compares total road user costs on all individual links and the proposed bypass. The bypass benefit calculation is shown by Equation 78.

*Equation 78: Bypass*

$$\text{BypassBenefits} = (RUC1_{BC} + RUC2_{BC} + \dots RUCB_{BC}) - (RUC1_{PC} + RUC2_{PC} + \dots RUCB_{PC})$$

Where:

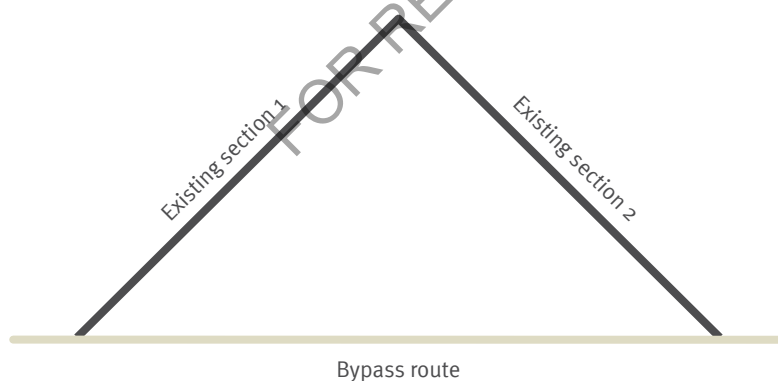
- Road user costs $1_{BC}$  = base case road user costs for existing section 1
- Road user costs $1_{PC}$  = project case road user costs for existing section 1
- Road user costs $B_{BC}$  = base case road user costs for the bypass section

Note: Road user costs $1_{BC} = (TTC_{BC} + VOC_{BC} + Acc_{BC})$ .

Road user costs are calculated based on road conditions and traffic volume for each individual road link and bypass section for both base and project cases. The calculation of road user costs for each existing road section and bypass section is consistent with the TTC, VOC and accident costs shown previously in Sections 4 to 6.

An example of a bypass project is shown by Figure 11 and Table 40. This example shows that without the bypass, road users only have the option of travelling along the existing sections. Once the bypass route is in place, some motorists who travel through the town will opt not to travel along the existing sections but alternatively choose to travel on the bypass route.

*Figure 11: Bypass*



To calculate the traffic breakdown of a bypass, attention is given to the amount of vehicles which divert from the existing sections to the bypass in a project case. For example, in the bypass case study shown in the *User Guide*, the breakdown is shown by Table 40.



Table 40: Bypass traffic breakdown example

	Existing 1		Existing 2		Existing 3		Existing 4		Bypass	
	Base	Project	Base	Project	Base	Project	Base	Project	Base	Project
AADT	4 000	2 000	8 000	6 000	8 000	6 000	4 000	2 000	0	2 000
Cars – private	82.0%	88.0%	82.0%	84.0%	82.0%	84.0%	82.0%	84.0%	0.0%	76.0%
Cars – commercial	11.0%	9.0%	11.0%	10.3%	11.0%	10.3%	11.0%	10.3%	0.0%	13.0%
Non-Articulated	3.3%	1.6%	3.3%	2.7%	3.3%	2.7%	3.3%	2.7%	0.0%	5.0%
Buses	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	0.0%	1.0%
Articulated	1.1%	0.2%	1.1%	0.8%	1.1%	0.8%	1.1%	0.8%	0.0%	2.0%
B-double	1.6%	0.2%	1.6%	1.1%	1.6%	1.1%	1.6%	1.1%	0.0%	3.0%
Road train 1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Road train 2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Growth rate (%pa linear)	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	N/A	3.0%

To estimate the project case vehicle breakdown, the number of vehicles that enter the bypass in the project case is derived from each existing section's breakdown, and is shown by Table 41.

Table 41: Bypass example – average annual daily traffic

	Existing 1		Existing 2		Existing 3		Existing 4		Bypass	
	Base	Project	Base	Project	Base	Project	Base	Project	Base	Project
AADT	4 000	2 000	8 000	6 000	8 000	6 000	4 000	2 000	-	2 000
Cars – private	3 280	1 760	6 560	5 040	6 560	5 040	3 280	1 680	-	1 520
Cars – commercial	440	180	880	620	880	620	440	207	-	260
Non-Articulated	132	32	264	164	264	164	132	55	-	100
Buses	40	20	80	60	80	60	40	20	-	20
Articulated	44	4	88	48	88	48	44	16	-	40
B-double	64	4	128	68	128	68	64	23	-	60
Road train 1	-	-	-	-	-	-	-	-	-	-
Road train 2	-	-	-	-	-	-	-	-	-	-

The number of vehicles which will divert to the bypass is the difference between the bypass project case and each existing section base case, as given by Equation 79.

Equation 79: Existing project case AADT

$$Existing_x AADT_{PC}(VT) = Existing_x AADT_{BC}(VT) - Bypass_{PC}AADT(VT)$$

Example: Existing project case AADT

In the bypass case study, AADT for the existing 1 for private cars is calculated as follows:

$$Existing\ 1\ AADT_{PC}(Private) = 3280 - 1520 = 1760$$

Existing private car AADT is converted to a percentage of total AADT.

$$\text{Existing 1 AADT}_{PC}\% (\text{Private}) = \frac{1760}{2000} * 100 = 88\%$$

*Example: Bypass*

Referring to Figure 11, a single B-double is currently travelling along two individual 10 km links (existing Sections 1 and 2), which will be bypassed under a new project. The single B-double is assumed to divert to the 7 km new bypass route. The aggregate discounted road user costs for the individual links are assumed to be \$525 000 and \$650 000 for existing Sections 1 and 2 respectively. When the bypass road is completed, the B-double is assumed to incur net discounted road user costs equal to \$750 000 for travelling along the bypass route. The total benefit of the bypass project is:

$$\text{BypassBenefits} = (525,000 + 650,000 + 0) - (0 + 0 + 750,000)$$

$$\text{BypassBenefits} = \$425,000$$

The above calculation shows that in the base case, the B-double only incurs road user costs for the existing Sections 1 and 2 as there are no road user costs for the bypass route in the base case, because the bypass route is assumed to be a new road (i.e. there is no bypass route in the base case).

However, in some instances the bypass route could be an existing road. This example also shows that in the project case the B-double only travels on the bypass route.

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# 4

## 9 Decision criteria

The decision criteria provide an indication of the economic performance of the proposal. This section provides the formula used to calculate the decision criteria employed in CBA6. The key decision criteria used in CBA6 include:

- BCR
- NPV
- FYRR
- NPVI
- IBCR

The BCR is the economic measure which is used to prioritise the selection of road projects. The BCR provides a single measure that can be used to support the decision to either accept or reject a project. In a budget constrained environment, the BCR can be used as a tool to rank and prioritise all projects in the budget pool. For this reason, the BCR is the preferred decision criterion for project economic justification.

The other decision criterion that provides decision makers with additional information is the NPV. Other indicators such as payback period and internal rate of return are not addressed in CBA6 or in this section. For further detail on why some indicators are used over others, see Section 1.7 of the *Theoretical Guide*.

Note: The principle of discounting is applied within each of these measures and is covered in Section 9.1. The residual value calculation used to calculate the value of the remaining life of the asset is discussed in Section 9.7, and is incorporated in the final year of the evaluation as a benefit.

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## 9.1 Discounting

Future flows of benefits and costs are discounted to reflect the time value of money, as discussed in Section 1.4 of the *Theoretical Guide*. The discounting formula is applied to both benefits and cost streams. Equation 80 shows the discounting formula used in CBA6.

*Equation 80: Discounting benefits*

$$\text{Present Value} = \frac{B_1}{1+r} + \frac{B_2}{(1+r)^2} + \frac{B_3}{(1+r)^3} + \dots + \frac{B_n}{(1+r)^n}$$

$$\text{Present Value} = \sum_{i=1}^n \frac{B_i}{(1+r)^i}$$

Where:

- $B_i$  = benefit or cost in year  $i$
- $n$  = number of years in the evaluation period
- $r$  = real discount rate

Table 42 shows a benefit flow of \$1000 in Year 1 followed by benefits of \$500 per annum until Year 5.

*Table 42: Discounting benefits*

Year	1	2	3	4	5	Total
Benefit (\$)	1000	500	500	500	500	3000
Discounted benefit (present value \$)	943	445	419	396	373	2577

*Example: Discounting benefits*

Assuming a 6% discount rate, the discounted total benefit is equal to:

$$\text{Total Benefit} = \frac{1000}{1.06^1} + \frac{500}{1.06^2} + \dots + \frac{500}{1.06^5}$$

$$\text{Total Benefit} = 2577.88$$

The results shown by Table 42 show that the benefit of \$500 earned in Year 2 is higher than the \$500 earned in Year 5 when compared to the present value. \$500 in Year 2 is equivalent to \$445 in present value while benefits of \$500 in Year 5 are only worth \$373 in present value.

## 9.2 Benefit-cost ratio

BCR is the discounted benefits divided by the discounted capital costs and the discounted net operating costs. The BCR is shown by Equation 81. The BCR will be greater than 1 whenever discounted benefits exceed discounted costs. A project with a BCR above 1 provides a net economic gain and can be considered economically justified. In a budget constrained environment, projects should be prioritised according to their BCRs. A project with a higher BCR provides a greater benefit per dollar invested and should receive priority in the allocation of funding. This will ensure the efficient allocation of scarce resources.

*Equation 81: Benefit-cost ratio*

$$BCR = \frac{\sum_{i=1}^n \frac{B}{(1+r)^i}}{\sum_{i=1}^n \frac{K_i + OC_i}{(1+r)^i}}$$

Where:

- $K_i$  = capital costs
- $OC_i$  = operating costs
- $R$  = discount rate
- $B$  = net benefits

*Example: Benefit-cost ratio*

If the sum of the discounted capital and operating costs is assumed to be \$50 million over the evaluation period and the discounted benefits are assumed to be \$70 million, then the BCR is given as follows:

$$BCR = \$70m / \$50m$$

$$BCR = 1.4$$

This example indicates that the present value of the benefits exceeds the present value of the costs required to build a project by 1.4 times.

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## 9.3 Net present value

NPV measures the actual or real net economic benefit of a project. While the BCR provides a ratio of benefits to costs, NPV measures the absolute net economic gain. NPV is calculated by subtracting the discounted costs from the discounted benefits. All projects with a positive NPV provide a net economic benefit. NPV should be used when comparing mutually exclusive project options. The option with the highest NPV is the preferred option.

*Equation 82: Net present value*

$$NPV = \sum_{i=1}^n \frac{(B_i - C_i)}{(1 + r)^i}$$

Where:

- $B_i$  = net annual benefits
- $R$  = discount rate
- $C_i$  = net annual costs

*Example: Net present value*

If the discounted total benefits are assumed to be \$70 million and the discounted total costs are assumed to be \$50 million, the NPV is:

$$NPV = \$70m - \$50m$$

$$NPV = \$20m$$

This result indicates that there has been a welfare improvement of \$20 million in net terms as a result of this project.

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## 9.4 First year rate of return

FYRR measures the economic return of a project in the first year of operation. FYRR is defined as the ratio of benefits in the first year divided by the capital costs of a project (including operating costs). If the FYRR is below the project discount rate, deferral of the project may be warranted to maximise the net economic gain.

*Equation 83: First year rate of return*

$$FYRR = \frac{B_{t_f}}{(1+r)^{t_f}} / \sum_{t=1}^{t_f-1} \frac{C_i}{(1+r)^t}$$

Where:

- $B_{t_f}$  = net benefits in the first year of operation
- $C_i$  = net capital costs

*Example: First year rate of return*

Using the 6% discount rate, if the first year net benefits of a project are \$2 million and the discounted total cost is \$50 million, then the FYRR is:

$$FYRR = \$2m / \$50m$$

$$FYRR = 4\%$$

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## 9.5 Incremental benefit-cost ratio

IBCR is generally used in options analysis.

*Equation 84: Incremental benefit-cost ratio*

$$IBCR = \frac{\sum_{i=1}^n \frac{Ba_i}{(1+r)^i} - \sum_{i=1}^n \frac{Bb_i}{(1+r)^i}}{\sum_{i=1}^n \frac{Ka_i + ICa_i}{(1+r)^i} - \sum_{i=1}^n \frac{Kb_i + ICb_i}{(1+r)^i}}$$

Where:

- $Ka_i$  and  $Kb_i$  = capital costs for option A and option B respectively
- $ICa_i$  and  $ICb_i$  = investment costs for option A and option B respectively

*Example: Incremental benefit-cost ratio*

IBCR compares the incremental benefits and costs of project option A to those of option B.

Discounted net benefits are assumed to be \$70 million and \$30 million for options A and B respectively, while the discounted net costs are assumed to be \$50 million and \$25 million for options A and B respectively. The IBCR is given by:

$$IBCR = (70 - 30)/(50 - 25)$$

$$IBCR = \frac{40}{25}$$

$$IBCR = 1.6$$

In this example project option A is preferred over option B. Every additional dollar spent on option A increases the net benefits of a project by \$1.60.

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## 9.6 Net present value per dollar investment

The NPVI, also known as the capital efficiency ratio, is the NPV of a project divided by the net capital cost of a project.

*Equation 85: Net present value per dollar investment*

$$NPVperDollarInvestment = \frac{\sum_{i=1}^n \frac{(B_i - C_i)}{(1+r)^i}}{\sum_{i=1}^n \frac{C_i}{(1+r)^i}}$$

Where:

- $B_i$  = net annual benefits
- $C_i$  = net annual cost

*Example: Net present value per dollar investment*

If the discounted net benefit of a project is \$70 million and the discounted net cost is \$50 million, the NPVI is:

$$NPVperDollarInvestment = (\$70m - \$50m)/\$50m$$

$$NPVperDollarInvestment = 0.4$$

The NPVI of 0.4 means that for each dollar invested, a contribution of \$0.4 is made to a project's NPV.

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## 9.7 Residual value

As mentioned in Section 2.3.3 of the *Theoretical Guide*, there are occasions where capital assets have a useful life beyond the life of the evaluation. To account for the benefit that the asset returns beyond the evaluation period, a residual value is calculated and applied in the last year of the evaluation as a negative cost.

The remaining life of the asset/project at the end of the analysis period should be expressed as a proportion of the total asset life. Multiplying the capital cost of a project by the proportion of remaining asset life to total asset life is one method of calculating the residual value of the asset. This value is then discounted in the final year of the evaluation.

*Equation 86: Residual value*

$$\text{ResidualValue} = \frac{\text{YearsRemain}}{\text{UsefulLife}} \times K$$

Where:

- YearsRemain = useful remaining life of the project (years)

*Example: Residual value*

The residual value of a \$100 million project with a useful life of 50 years over a 30-year analysis period is:

$$\begin{aligned}\text{ResidualValue} &= \frac{20}{50} \times \$100\text{m} \\ \text{ResidualValue} &= \$40\text{m}\end{aligned}$$

The result implies that additional benefits to the value of \$40 million will accrue to a project beyond the evaluation.

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# 4

## 10 Sensitivity testing

This section outlines the calculations used in sensitivity testing presented in the 'road case report' within CBA6. For further information on the 'road case report' see Section 4.6 of the *User Guide*. For further detail on the assumptions of sensitivity analysis, see Section 1.8.3 of the *Theoretical Guide*.

The standard sensitivity analysis in CBA6 recalculates BCR, NPV and FYRR subject to the following changes in inputs:

- capital costs  $\pm$  20%
- TTC  $\pm$  40%
- VOC  $\pm$  20%
- accident costs  $\pm$ 20%
- exclude private travel time costs.

Sensitivity testing shown in these sections is based on the following 'best estimate' assumptions:

- cost = \$50 million
- capital costs = \$40 million
- operating costs = \$10 million
- benefits = \$70 million
- TTC savings = \$40 million
- private TTC savings = \$1 million
- VOC savings = \$20 million
- accident savings = \$10 million
- first year benefits = \$2 million
- discount rate = 4%.

Under these assumptions of benefits and costs the BCR is 1.4, the NPV is \$20 million and the FYRR is 4%.

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## 10.1 Net present value

There are a number of key project inputs that can influence the NPV when they are subjected to some variability. These inputs have been described in Section 10.1.1.

### 10.1.1 Changes in capital cost

*Equation 87: Changes in capital cost (NPV)*

$$NPV = \sum_{i=1}^n \frac{B_i - C_i \times (1 \pm \Delta B)}{(1 + r)^i}$$

Where:

- NPV = net present value
- $B_i$  = total discounted benefits
- $C_i$  = total discounted costs
- $\Delta B$  = the percentage change in capital cost determined in the sensitivity analysis

*Example: Changes in capital cost (NPV)*

When the capital cost of a project, with discounted net benefits of \$70 million and discounted net costs of \$50 million, increases by 20%, the NPV is calculated as follows:

$$NPV = 70 - (40 \times 1.2) - 10$$

$$NPV = 70 - 58$$

$$NPV = \$12$$

Positive NPV indicates that despite the capital cost increase of 20% the project is still viable.

### 10.1.2 Changes in road user cost savings

The impact that changes in TTC, VOC and accident cost savings have on the NPV is shown by Equation 88.

*Equation 88: Changes in benefits (NPV)*

$$NPV = \sum_{i=1}^n \frac{(B_{ru} \times (1 \pm \Delta A) + B_{oi} - C_i)}{(1 + r)^i}$$

Where:

- $B_{ru}$  = road user cost savings (TTC, VOC or Acc)
- $\Delta A$  = the percentage change in  $B_{ru}$  determined in the sensitivity analysis
- $B_{oi}$  = benefits other than  $B_{ru}$

### Example: Changes in benefits (NPV)

If TTC increase by 40%, all other benefits and costs remain unchanged at \$20 million for VOC benefits, \$10 million for accident cost savings and \$50 million for costs. The resulting NPV is:

$$NPV = (40 * 1.40) + (20 + 10) - 50$$

$$NPV = \$36 \text{ million}$$

The NPV has increased from \$20 million under the normal scenario to \$36 million when TTC savings are increased by 40%. This is an increase in NPV of 80% compared to the best estimate. In this example, the NPV is very sensitive to changes in TTC savings.

### 10.1.3 Excluding private travel time costs

The impact that removal of private TTC savings has on NPV is calculated by Equation 89.

Equation 89: Excluding private TTC (NPV)

$$NPV = \sum_{i=1}^n \frac{(B_i - PTT C_i - C_i)}{(1 + r)^i}$$

Where:

- $PTTC_i$  = private travel time costs

Example: Excluding private TTC (NPV)

If a project has discounted net benefits of \$70 million, the private TTC component of that net benefit is \$1 million, and the net cost of the project is \$50 million, then the NPV excluding private travel time is:

$$NPV = 70 - 1 - 50$$

$$NPV = \$19 \text{ million}$$

Given the small amount of private TTC savings as a proportion of total benefits in this case, the change in NPV is not very sensitive to percentage changes in private TTC savings.

## 10.2 Benefit-cost ratio

The derivation of BCR throughout the sensitivity analysis is shown in Sections 10.2.1 to 10.2.3.

### 10.2.1 Changes in capital cost

The impact of a change in capital cost on the BCR is given by Equation 90.

*Equation 90: Changes in capital cost (BCR)*

$$BCR = \frac{\sum_{i=1}^n \frac{B_i}{(1+r)^i}}{\sum_{i=1}^n \frac{K_i \times (1 \pm \Delta B) + OC_i}{(1+r)^i}}$$

Where:

- $K_i$  = capital costs
- $OC_i$  = net operating costs

*Example: Changes in capital cost (BCR)*

With a 20% increase in capital cost with discounted net benefits of \$70 million, discounted net capital cost of \$40 million, and a discounted net operating cost of \$10 million, the BCR is:

$$BCR = 70 / (40 \times 1.20) + 10$$
$$BCR = \frac{70}{58}$$

$$BCR = 1.21$$

In this example, the BCR has decreased from 1.4 to 1.21 demonstrating that the project is not economically viable if capital cost was to increase by 20%.

Note: The BCR must be greater than 1 to justify the investment.

### 10.2.2 Changes in road user cost savings

The impact of a change in road user cost savings on the BCR is given by Equation 91.

*Equation 91: Changes in road user cost savings (BCR)*

$$BCR = \frac{\sum_{i=1}^n \frac{B_{ru} \times (1 \pm \Delta A) + B_{oi}}{(1+r)^i}}{\sum_{i=1}^n \frac{K_i + OC_i}{(1+r)^i}}$$

Where:

- $B_{ru}$  = road user cost savings (TTC, VOC or Acc)
- $B_{oi}$  = benefits other than  $B_{ru}$
- $\Delta A$  = percentage change in  $B_{ru}$  determined in the sensitivity analysis
- $K_i$  = capital costs

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- $OC_i$  = operating costs

*Example: Changes in road user cost savings (BCR)*

Where TTC savings increase by 40%, discounted net investment costs are \$50 million, VOC benefits are \$20 million and crash costs are \$10 million, the BCR is:

$$BCR = ((40 \times 1.4) + (20 + 10))/50$$

$$BCR = 1.72$$

The BCR of the project has changed from 1.4 to 1.72, an increase of 22% from the 'best estimate' as a result of a 40% increase in TTC savings.

### 10.2.3 Excluding private travel time costs

The removal of private TTC on the BCR is given by Equation 91.

*Equation 92: Excluding private travel time costs (BCR)*

$$BCR = \frac{\sum_{i=1}^n \frac{B_i - PTTC_i}{(1+r)^i}}{\sum_{i=1}^n \frac{K_i + OC_i}{(1+r)^i}}$$

Where:

- $PTTC_i$  = private travel time costs

*Example: Excluding private travel time costs (BCR)*

A project has discounted net benefits of \$70 million, the private TTC component of that net benefit is \$1 million, and the net cost of the project is \$50 million. The BCR excluding private TTC is:

$$BCR = (70 - 1)/50$$

$$BCR = 1.38$$

The BCR is reduced by 0.02 as a result of the escalating private TTC.

Note: The change in BCR is relatively small given the low proportion of private TTC savings.

## 10.3 First year rate of return

The derivation of FYRR sensitivity analysis is calculated through Sections 10.3.1 to 10.3.3.

### 10.3.1 Changes in capital cost

A change in capital cost on FYRR is shown by Equation 93.

*Equation 93: Changes in capital cost (FYRR)*

$$FYRR = \frac{B_{t_f}}{(1+r)^{t_f}} \bigg/ \sum_{t=1}^{t_f-1} \frac{C_i \times (1 \pm \Delta B)}{(1+r)^t}$$

Where:

- $B_{t_f}$  = total first year benefits
- $\Delta B$  = the percentage change in capital cost determined in the sensitivity analysis

*Example: Changes in capital cost (FYRR)*

A 20% increase in the capital costs of a project with discounted first year benefits of \$2 million, discounted net capital cost of \$40 million, and a discounted net operating cost of \$10 million, produces an FYRR of:

$$FYRR = 2 / (40 \times 1.2) + 10$$

$$FYRR = \frac{2}{58}$$

$$FYRR = 3.45\%$$

The 20% increase in capital cost lowers the FYRR from 4% to 3.45%.

### 10.3.2 Changes in road user cost savings

The impact that a change in road user cost savings has on FYRR is given by Equation 94.

*Equation 94: Changes in benefits (FYRR)*

$$FYRR = \frac{B_{RUf} \times (1 \pm \Delta A) + B_{t_0f}}{(1+r)^{t_f}} \bigg/ \sum_{t=1}^{t_f-1} \frac{C_i}{(1+r)^t}$$

Where:

- $B_{RUf}$  = first year of road user cost savings
- $\Delta A$  = the percentage change in  $B_{RUf}$  determined in the sensitivity analysis
- $B_{t_0f}$  = benefits other than  $B_{RUf}$

If first year TTC benefits increase by 40%, the FYRR becomes:

$$FYRR = (1 * 1.40) + (0.5 + 0.5) / 50$$

$FYRR = 4.8\%$

A 40% increase in road user cost savings in the first year increases the FYRR from 4% to 4.8%.

### 10.3.3 Excluding private travel time costs

The impact that removal of private TTC has on the FYRR is given by Equation 95.

*Equation 95: Excluding private travel time costs (FYRR)*

$$FYRR = \frac{B_{t_f} - PTT C_{t_f}}{(1+r)^{t_f}} \bigg/ \sum_{t=1}^{t_f-1} \frac{C_i}{(1+r)^t}$$

Where:

$PTTC_{t_f}$  = first year private TTC savings

*Example: Excluding private travel time costs (FYRR)*

A given project has discounted first year net benefits of \$2 million, a private TTC component of that net benefit of \$0.1 million, and a net cost of \$50 million. If private TTC savings are excluded the FYRR is:

$$FYRR = (2 - 0.1)/50$$

$$FYRR = 3.8\%$$

The removal of private TTC savings in the first year decreases the FYRR from 4% to 3.8%; this is below the cut off level at 4%.

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# 4

## 11 Effects of intermediate outputs

This section outlines the key relationships between intermediate outputs such as road roughness and speed, and the outputs of VOC and TTC.

*Table 43: Input and output relationships*

Input	Intermediary output	Output
Speed/roughness	Fuel	VOC
	Tyres	VOC
	Oil	VOC
	Interest and depreciation	VOC
	Repairs and maintenance	VOC
	Travel time	TTC

This analysis will examine the effects of changes in the intermediate outputs such as speed and roughness on the final outputs.

## 11.1 Vehicle operating costs

Table 44 shows the effects of a change in operating speed and current roughness on the outputs. This comparison differs with vehicle types, however it provides a general guide as to trends of output change, holding all other inputs constant.

Importantly, this example compares changes to a 'base case' as described in the examples throughout Section 4 i.e. a single B-Double travelling at 64.49 km/h on a curvy flat road with a VCR of 0.049.

As illustrated by Table 44, changes made in the intermediate outputs of speed and roughness have a significant effect on VOC in CBA6. When these costs are combined over multiple vehicle types and lengthy sections of motorway, their impacts become large in monetary terms.

*Table 44: Sensitivity testing of VOC components in respect to changes in intermediate outputs (B-doubles)*

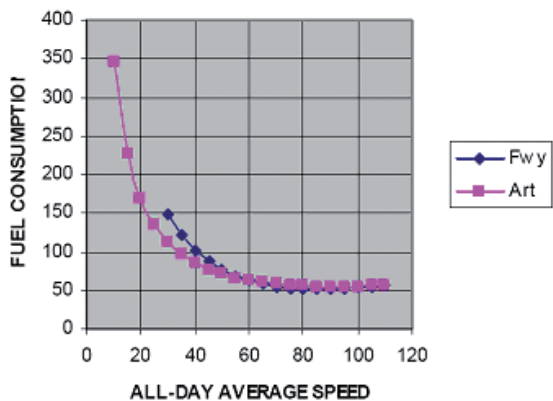
Outputs (c/km)	Base case		Intermediate output change		
	64.49km/h/ 120NRM	Change in speed		Change in roughness	
		40km/h	85km/h	30NRM	200NRM
Fuel	95.72	113.04	95.42	81.26	99.42
Oil	1.71	1.60	1.80	1.71	1.71
Tyres	49.58	47.00	52.60	49.58	49.58
Repairs and maintenance	24.93	24.93	24.93	20.60	29.87
Interest and depreciation	54.42	58.04	52.99	54.42	54.42
Total VOC unit cost	226.36	244.61	227.74	207.57	235.00

There are two important points to be noted from this comparison.

- 1 Table 44 illustrates trends in the calculation of fuel costs with regard to changes in roughness and speed. Fuel consumption and speed do not have a linear relationship. Moreover, fuel consumption reaches an efficiency frontier, when a marginal increase in speed produces an increase in fuel consumption. This trend is illustrated by Figure 12.
- 2 Fuel costs are sensitive to changes in road roughness. This point is based on the fuel consumption roughness adjustment (Equation 21) which becomes a proportionately larger adjustment as roughness increases (all other things being equal). Oil costs however, are only affected by speed and not by roughness. This is a result of Equation 25, which is derived solely on changes in speed. Similarly, the results in Table 44 show that interest and depreciation and tyre costs are based solely on changes in speed. This is a result of the net interest and depreciation equation (Equation 37), which includes operating speed to derive the final cost. However, changes in operating speed in the interest and depreciation calculation have a relatively small influence on the final unit VOC. The impact of changes in speed on tyre costs are greater and are a result of the roughness adjustment and the basic tyre wear equation (Equation 27).

It is important to note that changes in roughness do not affect tyre wear or tyre costs. The inclusion of a 'roughness adjustment' based on speed is the result of the assumption that lower operating speeds should reflect rough surface conditions.

Figure 12: Fuel consumption (B-Double)



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## 11.2 Travel time

The impact of speed on travel time is intuitive. The following calculation shows TTC for the road user.

*Equation 96: Trip time*

$$\text{TripTime}(VT) = \frac{\text{SecLength}}{\text{OS}(VT)}$$

As calculated in Section 5, trip time (hours) is then applied to vehicle cost per hour, which is reflective of the driver's time (for private vehicles), business costs and freight carried (commercial vehicles where appropriate).

Changes in road roughness have no effect on TTC, unless the vehicle's operating speed is also affected by the change in roughness. TTC are based purely on changes in operating speed.

*Example: Trip time*

A section length of a rural road remains constant at 5 km and a B-Double is travelling at 85 km/h. The time it takes for the B-Double to complete its journey is:

$$\text{TripTime}(VT) = \frac{5}{85} = 0.059\text{hrs}$$

Applying this trip time to the hourly time unit rate for a B-Double (\$48.40 from Table 23) yields TTC of \$2.86. Assuming that the B-Double travels the same section length at a speed of 45 km/h, TTC increase to \$5.38. When operating speed decreases by 53%, TTC increase by 88%. There is an inverse relationship between the change in speed and the change in TTC.

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