TRANSPORT AND INFRASTRUCTURE COUNCIL

Australian Transport Assessment and Planning Guidelines

Worked Example: W4 Active Travel

4.2 Missing cycleway segment

August 2019

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For enquiries or feedback about this publication please contact:

ATAP Steering Committee Secretariat
Australian Transport Assessment and Planning Guidelines
Commonwealth Department of Infrastructure, Regional Development and Cities
GPO Box 594 CANBERRA ACT 2601
Email: atap@infrastructure.gov.au

This publication is available from the website atap.gov.au

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1. Problem description

In this example, an incomplete off-road cycleway currently exists, with a segment missing near its middle. Currently, trips wanting to use both of the existing segments of the cycleway must leave the cycleway and use adjacent on-road cycle lanes for the part of their trip of the missing segment. This limits the overall effectiveness of the cycleway.

The initiative being assessed is the completion of the missing cycleway segment. Completion of the missing link will eliminate perceived impediments to cycling for work and study trips. The missing link is the same length as the adjacent on-road cycle lanes and connects a cluster of residential colleges near a university with the centre of the campus. The cycleway is intended as a high speed link open only to cyclists; one of the objectives of completion of the cycleway is to increase the uptake of cycling.

2. Options

The example examines a single project case option in addition to the base case.

Base Case

Option 0: Do Nothing: The base case is the existing transport network which includes:

- The incomplete off-road cycleway
- The on-road cycle lanes adjacent to the missing cycleway link that connect the existing cycleway segments.

No further improvements are available for the on-road part of route as a do minimum improvement.

Project Case Options

Option 1: In the project case the cycleway is completed by eliminating the missing link.

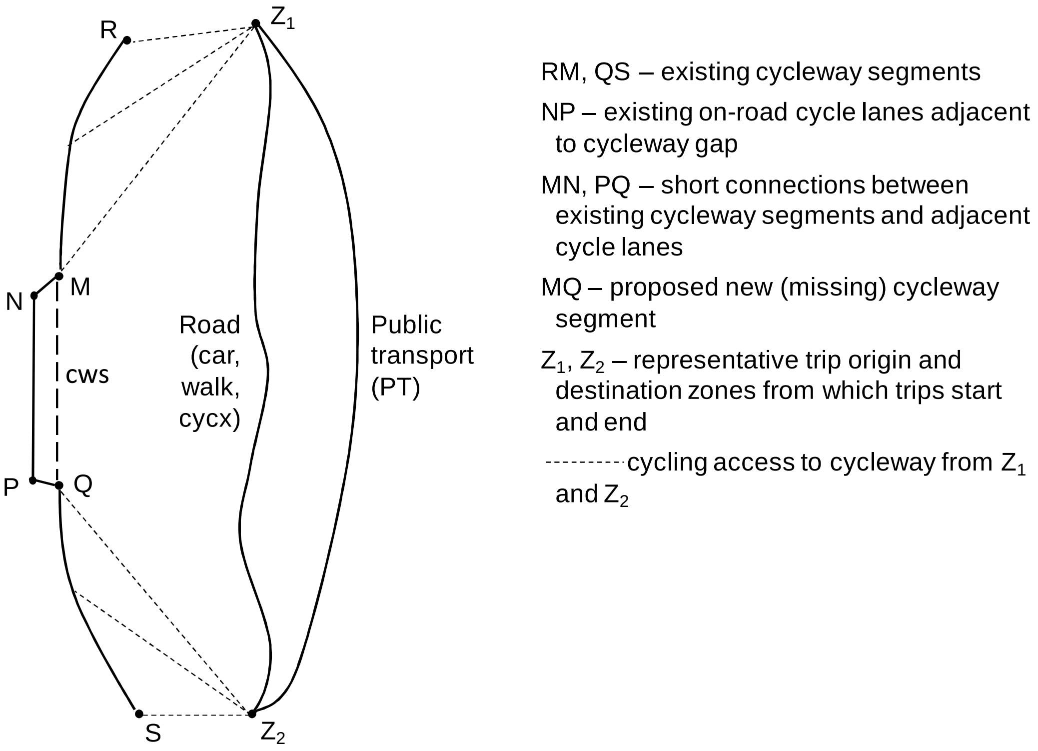
In the remaining discussion the terms Base Case and Project Case are shortened to BC and PC.

Figure 1 presents the situation. For travel between zones Z_1 and Z_2 , people face a choice of several options for making their trips. They can travel by any of the following options:

- Car: by route Z_1roadZ_2
- Public transport (PT): by route Z_1PTZ_2
- Walking: on the local road and/or path network (for simplicity in Figure 1 denoted as also occurring along route Z_1roadZ_2)
- Cycling along the cycleway route (denoted ‘CWS’):
  - In the BC along route Z_1MNPQZ_2 – the route using the adjacent on-road cycle lane and could include part or full use of the existing cycleway. The short access links MN and PQ are included to allow for the inconvenience experienced by cyclists in transferring from the cycleway to the road and back again, i.e. a small time penalty
  - In the PC along route Z_1MQZ_2 – the cycling route which includes the new cycleway segment and could include part or full use of the existing cycleway

- Cycling on the local road and/or paths network (denoted 'CYCX').

Figure 1: Cycleway situation and travel choice options



3. Benefits and costs

The initiative reduces the cost of travel using the cycleway segment in two ways:

- – It is safer than the adjacent on-road cycle lanes
- – Travel time is faster than on the adjacent on-road cycle lanes.

This is expected to result in new cycleway trips:

- Diverted trips switching out of other transport modes: car, public transport, walk, cycling on the local road / path network
- New cycleway trips not previously undertaken by another transport mode.

Table 1 lists the benefits and costs and whether they have been monetised. The benefits are explained as follows:[1]

[1] The benefit estimation methodology and assumptions are discussed in section 4, benefit calculations are documented in section 8, and appendix A4 provides a more in depth explanation regarding new trips.

- Existing trips using the adjacent on-road cycle lanes in the BC benefit in the PC by the reduced travel cost (improved safety and reduced travel time) afforded by the new cycleway segment
- The new cycleway trips in the PC benefit because the marginal cost (perceived generalised cost) has dropped below their marginal benefit (marginal willingness to pay), resulting in a net gain.
- Health system benefits[2] (savings in costs to the health system, and separate to private health benefits) arise from cyclists diverting from car and public transport
- Road decongestion benefits and environmental benefits from the trips that switch from car to cycleway
- Non-monetised benefits are:
  - The landscaping installed as part of the cycleway construction will provide amenity benefits for cyclists and for users of the park through which the cycleway passes. Their estimation is unlikely to be justified by the size of the initiative so are simply listed as non-monetised.

Table 1: Monetised and non-monetised benefits and costs

	Monetised	Non-monetised
Benefits		
To existing cycling trips:		
Crash cost savings	✓	
Time savings	✓	
To new cycling trips (using rule-of-a-half):		
Diverted from car, public transport, walk and local road cycling	✓	
Newly generated	✓	
Health system benefits	✓	
Road decongestion	✓	
Environmental	✓	
Landscaping amenity		✓
Costs		
Construction costs	✓	
Maintenance costs	✓	

[2] ATAP Part M4 (Tables 13 and 14) distinguishes between two categories of health costs: private health costs borne and by the user, and health system costs not borne by the user. The former are accounted for in calculating the benefits to new cycling trips using the 'rule-of-a-half', while changes in the latter are expressed as separate health system benefits.

Note: The benefit to new cycleway trips consists of the combined changes in perceived user costs (time costs, vehicle operating costs, safety costs and private health costs) that arise from using the cycleway in the project case compared to their base case choices.

4. Inputs and assumptions

Base year and price year: 2015

Real discount rate: 7%

Construction period years: 2016

Construction cost: $1.65 million (1.1 km segment at a unit cost of $1.5m per km)

Asset (economic) life: 30 years

Appraisal period: Construction period plus 30 benefit years

Residual value:

Nil – asset life equals benefit period

Maintenance costs:

$5,000 per year – the incremental annual maintenance costs compared to the BC.

Trip types

It is estimated that 5% of the existing cycling trips are business trips undertaken during work (employer's business). A higher value of time savings applies for these trips.

Estimation of the number of new cycleway trips:

Estimation of the increase in active travel trips resulting from active travel improvements is not straight forward as there is limited guidance in the literature. The approach taken here has been to assume that the initiative increases the number of cycleway trips by 20%.[3]

Benefit estimation methodology:

Benefits have been calculated using standard methodology as set out in the Guidelines. ATAP Part T2 Chapters 6 to 9 provide a generic derivation of methodology and benefit formulas.

With respect to new cycleway trips, as explained in section 3, the net gain for each new trip is the difference between its marginal willingness to pay and the generalised cost. The standard methodology for estimating the net gain involves application of the 'rule-of-a-half' (ATAP Part T2 Chapter 6, ATAP Part M4 section 5.1.1). Section 8 shows calculations and Appendix A provides a detailed supporting discussion.

[3] Using the inputs of this worked example, the 20% increase assumption is equivalent to a generalised cost elasticity of –0.5.

Note that in both ATAP public transport worked examples (see ATAP Part W1), the benefits to new trips have been calculated in the same way, using the rule-of-a-half. Its use applies to all transport modes.

Perceived user costs:

Application of the 'rule-of-a-half' for new trips accounts for the benefit contribution of all perceived cost components. For unperceived costs, benefit calculations do not involve the 'rule-of-a-half', with cost changes translating fully into benefits. The assumptions about cost perception adopted here are:

- Perceived user costs: time, safety, private health costs, money operating costs and modal preferences
- Unperceived costs: All other costs, including health system costs.

Application across all O-D pairs:

Figure 1 shows a representative pair of origin (O) and destination (D) zones. Best practice in transport appraisal requires:

- Calculation of the benefit for each O-D pair in the trip matrix for the region
- Adding up the results across all O-D pairs.

Such an approach is important because it takes into account any network / congestion effects across the rest of the network. See ATAP Part T2 section 7.3 for a general discussion.

However, it is usually the case in practice that a cycling trip matrix is unavailable. In addition, cycling congestion effects across the network are generally considered small. For assessing cycling initiatives it is therefore typically the case that the change in travel cost for each O-D pair can be reasonably approximated by the change in travel cost at the immediate location of the initiative – in this case the cycleway segment MQ in Figure 1.

Indirect effects:

The switching that occurs to the cycleway in the PC can result in some indirect effects on the other travel options. The following assumptions are made for this worked example:

- Public transport (PT): It is assumed that there is no change in any PT travel cost component in going from the BC to the PC. When some PT users in the BC switch to the cycleway in the PC, there is in-principle a reduced crowding benefit for remaining PT users, but this effect is expected to be negligible
- Car: As switching occurs from car to cycleway between BC and PC, a number of indirect effects occur:
  - For the remaining cars on the road network, time costs and vehicle operating costs will decrease due to road decongestion effects. Decongestion benefits have been estimated using ATAP Part M1 Table 11 (p.38). The unit decongestion benefit used of $0.50 represents an indicative weighted average across the time periods in the table in M1
  - For the community more generally, there are environmental benefits. These are estimated on a per car-km basis
  - For transport agencies, there may be savings in road maintenance costs, although these are expected to be negligible.
- Walking and cycling on local roads/paths: No changes in GC are expected for these travel options between BC and PC, hence no benefits

Growth rate: 2% per annum over the appraisal period

Other:

For car and public transport trips in the BC we assume that:

- The location of parking allows door to door access at each car trip end so that walk component of each car trip is negligible
- A total walk distance of 0.4 kms for bus trips, used in calculating health system benefits.

Table 2 lists other inputs and assumptions.

Table 2: Other initiative inputs and assumptions

		Source
Trip type	work (5%)/study	
Number of cycleway trips in BC	300 trips per day	
% Increase in cycleway trips in PC	20%	
Source of new cycling trips:		
Newly generated	20%	
Diverted from other modes:	80%	
- from car	20% (25% of 80%)	
- from public transport	60% (75% of 80%)	
Benefit days per year	250 days per year	
Average trip length	5 kms	ATAP 2015, M4, p.12
Growth rate	2%	
Travel speeds::		
Trip segment – missing cycleway segment:		
Adjacent on-road cycle lane	23 kms/hr	ATAP 2015, M4, p.63
Cycleway	25 kms/hr	ATAP 2015, M4, p.63
Trip segment – rest of trip:		
On road (door-to-door)	16 kms/hr	ATAP 2015, M4, p.63
Existing cycleway	25 kms/hr	ATAP 2015, M4, p.63
Access time delay at start/end of segment (in BC)	1 min	
Average value of time savings – active travelers (2013):		
Work (employer's business) trips	$48.63 per person-hr	ATAP 2015, PV2, p.19
Study trips	$14.99 per person-hr	ATAP 2015, PV2, p.19
Crash cost per km cycling (2013, willingness to pay))	$0.95 per cycling-km	ATAP 2015, M4, p.56
Crash reduction factors compared to average cycling crash cost:		
Adjacent cycle lanes (in BC)	30%	ATAP 2015, M4, p.51
Cycleway (in PC)	90%	ATAP 2015, M4, p.51
Health system benefit of active travel (2013)		
Cycling	$0.48 per cycling-km	ATAP 2015, M4, p.46
Walking	$0.97 per walking-km	ATAP 2015, M4, p.46
Unit road decongestion cost	$0.50 per car-km	ATAP 2018, M1, p.38
Unit environmental cost	$0.11 per car-km	Austroads 2012, p.26
CPI: June 2013, June 2015	102.8, 107.5	ABS, 6401.0
AWE: June 2015, June 2015	1420.9, 1483.1	ABS, 6302.0
For portion of cycling trip away from missing cycleway segment:		
% of trip on road	50%	
% of trip on existing cycleway	50%	

Table Note: Any input without a specific reference is an assumption for the analysis

Table 3: Annual benefit and cost time streams

Year	Costs			Benefits									Net Benefits
				Existing cycling trips		New cycling trips							
	Capital	Maintenance	Total	Crash reduction	Time savings	Diverted	Generated	Health system benefits	Road decongestion	Environmental	Residual value	Total	
2016	1650		1650										-1650
2017		5	5	49	27	6	2	34	8	2		127	122
2018		5	5	50	27	6	2	35	8	2		129	124
2019		5	5	51	28	6	2	35	8	2		132	127
2020		5	5	52	28	6	2	36	8	2		134	129
2021		5	5	53	29	7	2	37	8	2		137	132
2022		5	5	54	30	7	2	38	8	2		140	135
2023		5	5	55	30	7	2	38	8	2		143	138
2024		5	5	56	31	7	2	39	9	2		145	140
2025		5	5	58	31	7	2	40	9	2		148	143
2026		5	5	59	32	7	2	41	9	2		151	146
2027		5	5	60	33	7	2	41	9	2		154	149
2028		5	5	61	33	8	2	42	9	2		157	152
2029		5	5	62	34	8	2	43	10	2		161	156
2030		5	5	64	35	8	2	44	10	2		164	159
2031		5	5	65	35	8	2	45	10	2		167	162
2032		5	5	66	36	8	2	46	10	2		170	165
2033		5	5	68	37	8	2	47	10	2		174	169
2034		5	5	69	37	9	2	48	11	2		177	172
2035		5	5	70	38	9	2	49	11	2		181	176
2036		5	5	72	39	9	2	50	11	2		185	180
2037		5	5	73	40	9	2	51	11	2		188	183
2038		5	5	75	41	9	2	52	11	3		192	187
2039		5	5	76	41	9	2	53	12	3		196	191
2040		5	5	78	42	10	2	54	12	3		200	195
2041		5	5	79	43	10	2	55	12	3		204	199
2042		5	5	81	44	10	2	56	12	3		208	203
2043		5	5	82	45	10	3	57	13	3		212	207
2044		5	5	84	46	10	3	58	13	3		216	211
2045		5	5	86	47	11	3	59	13	3		221	216
2046		5	5	87	47	11	3	60	13	3	0	225	220
PV (7%)	1,542	58	1,600	700	381	87	22	484	107	24	0	1,804	204
Share	96%	4%	100%	39%	21%	5%	1%	27%	6%	1%	0%	100%	

(1) PV = present value

(2) All figures (except PV and share) are in undiscounted $ 000 units.

5. Benefit and cost time streams

Annual benefit streams are shown in Table 3 and Figures 2 to 4

Figure 2: Total benefits time stream

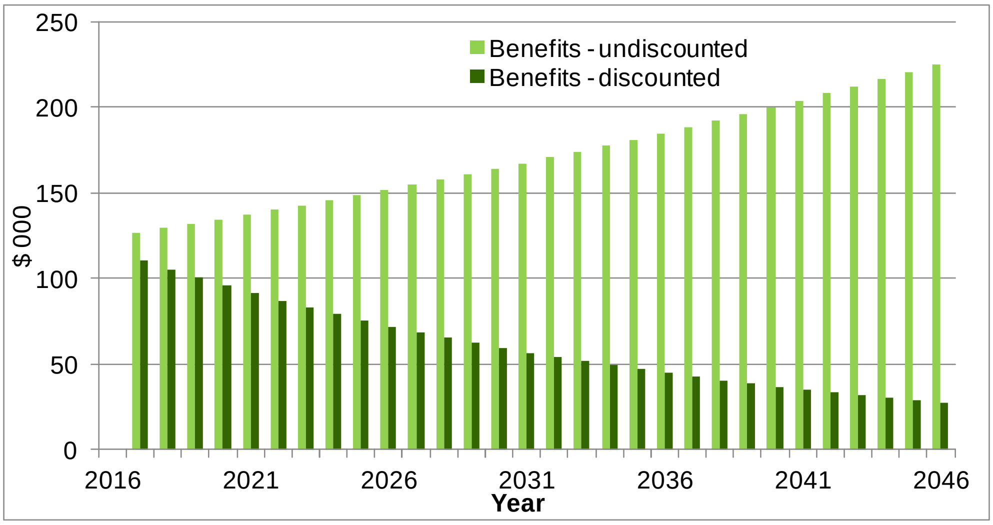


Figure 3: Total costs time stream

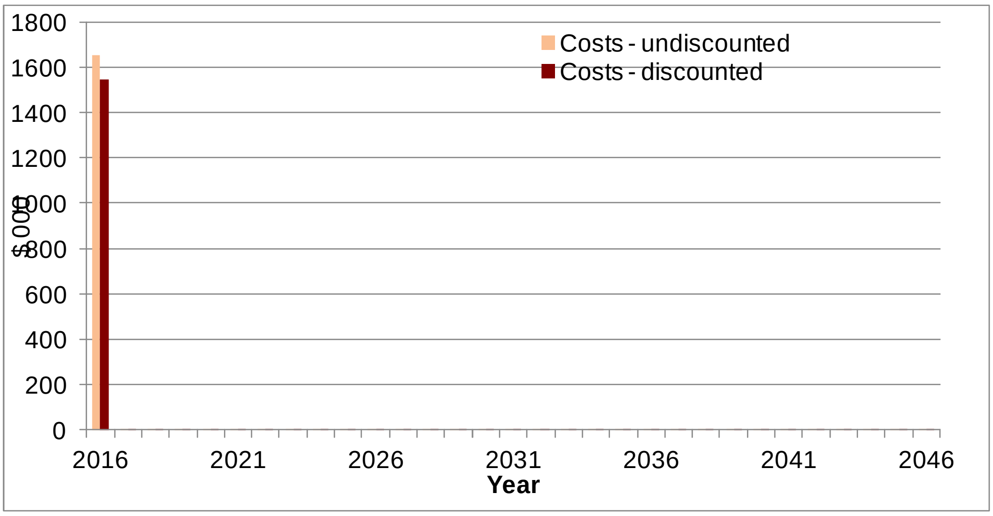
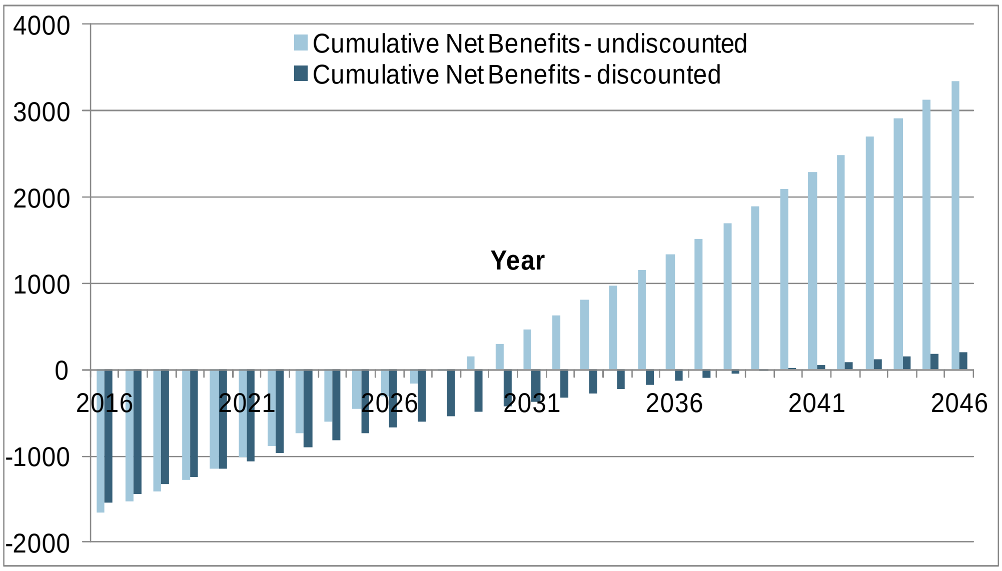


Figure 4: Net benefits time stream



6. Results summary

Table 4: Benefit and cost results – Central assessment (7% discount rate, input value best estimates)

	Present Value $000
Benefits	
Existing cycling:	
Crash cost savings	700
Time savings	381
New cycling trips:	
Diverted from car and public transport	87
Newly generated	22
Health system benefits	484
Road decongestion	107
Environmental	24
Residual value	0
Total, PVB	1,804
Costs	
Capital, PVIC	1,542
Maintenance, PVOC	58
PVC = PVIC + PVOC	1,600
Results	
NPV = PVB – PVC	204

	Present Value $000
BCR1 = PVB / PVC	1.13
BCR2 = (PVB – PVOC) / PVIC	1.13
FYRR (%)	7%

Table Notes:

1. All benefit and cost components are calculated as the incremental change between Base Case and Project (Option) Case
2. PV stands for present value; PVB is the PV of economic, social and environmental benefits, includes residual value, and excludes operating and maintenance costs; PVOC is the PV of operating and maintenance costs; PVIC is the PV of investment (i.e. capital) costs
3. BCR definitions BCR1 and BCR2 are both used by Australian jurisdictions – see ATAP Part T2 section 10.

Table 5: Sensitivity testing results

	PVB	PVIC	PVOC	NPV	BCR1	BCR2	IRR	FYRR
Central assessment (7% discount rate,	1,804	1,542	58	204	1.13	1.13	8.1%	6.9%
Sensitivity Tests(4)								
1. Low discount rate (4%)	2,689	1,587	83	1,019	1.61	1.64	8.1%	7.1%
2. High discount rate (10%)	1,290	1,500	43	-253	0.84	0.83	8.1%	6.7%
3. Increase capital costs by 25%	1,804	1,928	58	-181	0.91	0.91	6.1%	5.5%
4. Decrease capital costs by 5%	1,804	1,465	58	281	1.18	1.19	8.6%	7.3%
5. Increase maintenance costs by 10%	1,804	1,542	64	198	1.12	1.13	8.1%	6.9%
6. Decrease maintenance costs by 10%	1,804	1,542	52	210	1.13	1.14	8.2%	6.9%
7. Increase benefits by 10%	1,984	1,542	58	384	1.24	1.25	7.1%	7.6%
8. Reduce benefits by 25%	1,353	1,542	58	-247	0.85	0.84	5.5%	5.1%
9. Trip length 3 kms	1,479	1,542	58	-121	0.92	0.92		5.6%
10. Trip length 7 kms	2,013	1,542	58	413	1.26	1.27		7.7%
11. Diverted trips 75% from car	2,041	1,542	58	441	1.28	1.29		7.8%
12. Newly generated trips 80%	1,687	1,542	58	87	1.05	1.06		6.4%
13. Work (employer's business trips) 10%	1,846	1,542	58	246	1.15	1.16		7.1%

7. Results discussion

The results demonstrate that the initiative is economically viable for the central (most likely) CBA assessment case, which produces an NPV of $146,000 , with BCR1 = 1.09 and BCR2 = 1.09.

The sensitivity tests show that the viability of the initiative is dependent on the assumptions used. For the standard sensitivity tests (1 to 8) the BCR falls below 1.0 for the following cases: 10% discount rate, the 25% increase in capital costs, the 25% reduction in benefits. For the additional sensitivity tests, BCR is less than 1.0 for the shorter trip length assumption – the assumption results in a smaller reduction in car kms and hence lower health system benefits, road decongestion benefits and environmental benefits.

8. Supporting formulas and calculations

The benefit formulas and their calculation are provided below (see note on benefit estimation methodology in section 4). Some general points to note are:

- Unit costs in 2013 $s are indexed to June 2015 $s (the price year) using the Australian Bureau of Statistics Consumer Price Index (CPI) and Average Weekly Earnings (AWE) as follows:
  - Unit crash costs are multiplied by CPI June 2015 / CPI June 2013 = 107.5 / 102.8 = 1.046
  - Unit value of travel time savings are multiplied by AWE June 2015 / AWE June 2013 = 1483.1 / 1420.9 = 1.044
- The calculations are of benefits for year 2017
- Benefits for 2018 and onwards are calculated by increasing from the 2017 result by the growth rate (2%) each year, i.e. multiply by (1+ Growth rate/100) for each subsequent year.

Formulas

- Existing trips:
  - Crash reduction benefit = crash cost reduction per trip * annual number of trips
  - Time savings benefit = time saving benefit per trip * annual number of trips
- New cycling trip benefit = benefit per trip * annual number of trips

  where, benefit per trip = 0.5 * benefit per trip for existing cycle trips, i.e. application of the 'rule-of-a-half' (see discussions in section 4 and Appendix A).

- Health system benefits = benefit gain from increased cycling kms –benefit lost from less walking to public transport stops
- Road decongestion benefits = unit decongestion benefit per car-km * number of diverted car-kms
- Environmental benefit = unit environmental benefit per car-km * number of diverted car-kms

Calculations

For existing trips

300 one-way cycleway trips per day

250 cycling days per year

75,000 trips per year (300 * 250)

1.1 kms – length of affected cycleway travel (i.e. length of new cycleway segment)

Safety

$0.993 – average unit crash rate per cycling-km on roads indexed to 2015 $s ($0.95 * 1.046)

0.3 - crash reduction factor for on-road cycle lane in BC

$0.695 – on-road cycle lane unit crash cost per cycling km (0.993 * ([1 – 0.3])

0.9 – crash reduction factor for cycleway in PC

$0.099 – cycleway unit crash costs (0.993 * [1 – 0.9])

$0.656 – unit crash cost benefit of improvement per trip ([0.695 – 0.099] * 1.1)

$49,200 – annual crash reduction benefit (0.656 * 75,000)

Travel time

23 kms/hr - BC speed on on-road cycle lane

25 kms/hr – PC speed on cycleway

1 min – time delay on connector links MN & PQ

1.23 mins/trip – time saving per trip ([1.1/23 + 1/60] – 1/25]) * 60)

$50.77 – value of time savings: work (employer's business) trips indexed to 2015 $s ($48.63 * 1.044)

$15.65 – value of time savings per person hour for (14.99 * 1.044)

$17.41 – weighted value of time savings across all trips (50.77 * 0.05 + 15.65 * 0.95)

$0.357/trip – time saving benefit per cycleway trip (1.23 /60 * 17.41

$26,775 – annual time savings benefit (0.357 * 75,000)

Safety + Travel Time combined

$1.013 – benefit per trip (0.656 + 0.357)

$75,975 ($1.013 * 75,000)

For switchers from car and PT

15,000 new cycleway trips per year from BC to PC (75,000 * 20%)

12,000 trips per year of new cycleway trips switch from another transport mode (80% of new cycling trips, 15,000 * 0.8)

3,000 trips per year switch from car to cycleway (25% of 12,000)

9,000 trips per year switch from PT to cycleway (75% of 12,000)

$1.013 – benefit per trip for existing cyclists (see above)

$0.5065 – average benefit per trip for switchers (1.013 * 0.5 – by rule-of-a-half)

$1,520 – annual benefit to switchers from car (0.5065 * 3,000)

$4,559 – annual benefit to switchers from PT (0.5065 * 9,000)

For generated trips, i.e. switching from 'not travelling' to 'travelling by cycle'

3,000 trips are newly generated per year (20% of new cycleway trips, 15,000 * 0.2)

$0.5065 – benefit per trip – same as for modal switchers

$1,520 – annual benefit to generated traffic (0.5065 * 3,000)

Combined benefits to cyclists

$75,975 – to existing trips

$7,599 – to new cycleway trips (1,520 + 4,559 + 1,520)

$83,574 – total annual benefit to cyclists (75,975 + 7,599)

Health System Benefits, HCs

$0.502 – unit health system benefit per cycling-km (0.48 * 107.5 / 102.8)

5 kms – average trip length of new cycleway trips

75,000 – new cycleway-kms per annum (15,000 * 5)

$37,650 – annual health system benefit from new cycleway trips (75,000 * 0.502)

$1.01 – unit health system benefit per walking-km

0.4 – distance walked to/from bus stop for PT trips

3,600 – reduced walking-kms from switch away from PT (9,000 trips * 0.4)

$ 3,636 – annual health system disbenefit from reduced walking (3,600 * 1.01)

$34,014 – *net* health system benefits of new cycleway trips (37,650 – 3,636)

Decongestion benefits to remaining car users in PC

3,000 trips – annual car trips that switch to cycling (see above)

5 kms – average trip length for switching trips

15,000 – annual reduction in car-kms (3,000 * 5)

$0.5 – average unit decongestion benefit per car-km (ATAP, M1, p.38)

$7,500 – annual decongestion benefit (15,000 * 0.5)

Environmental benefits of reduced car travel in PC

15,000 - annual reduction in car veh-km (from above)

$0.11/car-km - unit environmental cost of car use (Austroads 2012)

$1,650 – annual environmental benefit of switching from cars (15,000 * 0.11)

Appendix A Supporting notes on calculating benefits to new cycleway trips

As discussed in section 4 above, the net gains for new cycleway trips have been calculated using the standard 'rule-of-a-half' methodology. The rule-of-a-half is a key aspect of standard cost-benefit analysis but is not widely familiar to, or well understood by, non-economists. The supporting discussion in this appendix aims to increase the level of understanding across users of the ATAP Guidelines.

Section A.1 briefly summarises and explains the standard benefit estimation methodology for new cycleway trips, culminating in use of the 'rule-of-a-half' to estimate the net gain to those trips. In section A.2, the link is demonstrated between the net gain for those trips and the associated gains and losses in individual cost components.

The key points are:

- The 'rule-of-a-half' measures the *net* gain to new cycleway trips and is therefore the correct measure to use in a cost-benefit analysis of an initiative
- By definition, the *net* gain is also the sum of all the individual component gains and component losses. Application of the 'rule-of-a-half' therefore produces a comprehensive measure of net gain, with all component gains and losses taken into account.

A.1 Summary of standard methodology

Section A.1.1 set out the drivers of user choice. Sections A.1.2 and A.1.3 below explain the key concepts of GC, travel demand curve and willingness to pay. Sections A.1.4 and A.1.5 bring the concepts together to explain the user choices and user benefits associated with the cycleway improvement. Section A.1.6 then explains how the 'rule-of-a-half' provides an easy to apply approximation of the benefits to new cycleway trips. Section A.1.7 states the user benefit formulas and Section A.1.8 applies them to the worked example.

A.1.1 Travel choice drivers

Figure 1 showed that travellers could choose between a number of travel options: car, public transport (PT), walk, use of the new cycleway segment (denoted cws) and use of the local road network and cycle paths (denoted cycx). In making their travel decisions, users consider:

- The generalised cost (GC) that they face making a trip by various modes (GC_{CWS}, GC_{CAR}, GC_{PT}, GC_{CYCX} and GC_{WALK}), and
- Their willingness to pay (WTP) to make that trip by the various modes (WTP_{CWS}, WTP_{CAR}, WTP_{PT}, WTP_{CYCX} and WTP_{WALK}).

Users look at all of that information and make their travel choices. That is the basis of best practice travel demand modelling as explained across relevant ATAP Parts including T1 Demand Modelling, M1 Public Transport and M4 Active Travel.

A.1.2 Generalised cost

The generalised cost (GC) of travel:

- Is the combined money and non-money private / personal costs users face
- As perceived by the user.

GC is the sum of various cost components:

$GC = TC + SC + HC_P + MC + OC$

where:

TC = time cost

MC = money cost (vehicle operating costs, fares, tolls, parking charges, etc)

SC = safety cost

HC_P = perceived private health cost to the user

OC = other costs – we use this category here to represent the relative cost of personal likes and dislikes about travelling by one transport mode vs another, e.g. “I just don’t like travelling on buses” or “I refuse to cycle when it’s raining”; termed ‘mode specific constant’ in M1 Public Transport

Each component is in $ per trip units.

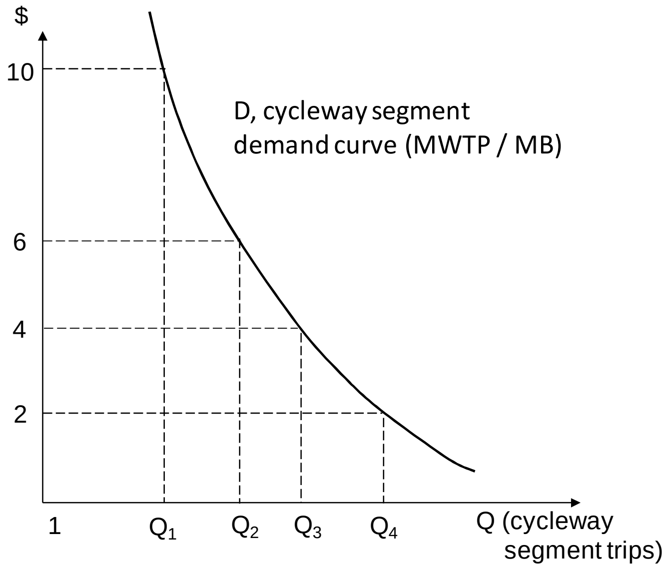
A.1.3 Travel demand curve and willingness to pay

Figure 5 shows the demand curve for the missing cycleway segment. It tracks how the number (quantity) of trips using the cycleway segment varies with the price of undertaking those trips as measured by GC_{CWS} . As the price changes we move along the demand curve.

The demand curve is downward sloping, generally what we observe across society. That is, ‘other things being equal’, as the price of a good or service decreases, the greater the quantity of consumption / use that is observed.

Figure 5 illustrates four price / quantity combinations: (10, Q_1), (6,Q_2), (4,Q_3), (2,Q_4).

Figure 5: Cycleway segment demand curve



The demand curve reflects the willingness to pay (WTP) by potential cyclists to make cycleway segment trips when faced with various GC_{CWS} levels. The height of the demand curve equals the marginal WTP (MWTP), i.e. the change in WTP for the additional / marginal trip being undertaken on the cycleway segment. At any point in time, trips are attracted to the cycleway segment until MWTP = GC_{CWS}. So:

- If GC_{CWS} = \$10, Q_1 trips are made and for the marginal trip MWTP = \$10
- If GC_{CWS} = \$6, Q_2 trips are made and for the marginal trip MWTP = \$6, etc

When there is a decrease in GC_{CWS}, the additional / new trips on the cycleway segment are of two types:

- *Diverted trips (mode switching)*: Trips previously made by another travel mode, but are now made using the cycleway segment — the person has switched from making that trip by car, public transport, walking or cycling on local roads/paths, to making it by using the cycleway segment
- *Generated cycleway trips*: Totally new trips not previously made by any travel mode. To maintain the 'switching' mindset, it is convenient to refer to these as cases where switching has occurred from one type of behaviour to another – from 'not travelling at all' to 'travelling on the cycleway'.

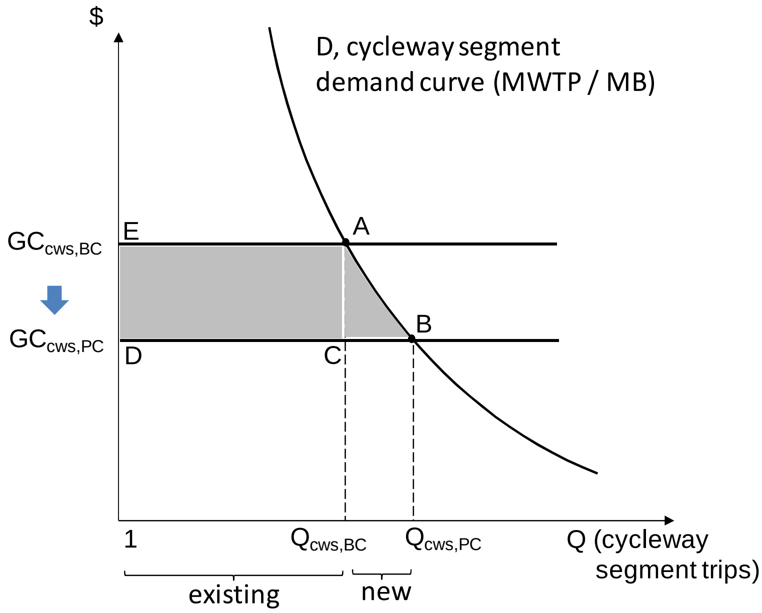
Note that WTP is another way of saying the value to the user. So the MWTP is the marginal value, or marginal benefit (MB), of an additional / marginal trip. The height of the demand curve therefore measures the MB to the marginal trip.

A.1.4 Effect of the cycleway improvement

We now introduce the cycleway improvement. The discussion below compares the BC and PC situations. The term 'cycleway segment' is used generically to refer to both: the adjacent cycle lanes in the BC, and the new cycleway segment in the PC.

Consider Figure 6, which is a repeat of Figure 5 with GC_{CWS} curves added for the BC and PC. In the BC, we are positioned at point A on the demand curve. The improvement causes a reduction in GC_{CWS} from $GC_{CWS,BC}$ to $GC_{CWS,PC}$. This makes use of the cycleway more attractive, resulting in a move along the demand curve from point A to point B in Figure 6, with the number of cycleway segment trips increasing from $Q_{CWS,BC}$ to $Q_{CWS,PC}$, and the number of new cycleway segment trip being ($Q_{CWS,BC}$ – $Q_{CWS,PC}$).

Figure 6: Impact of cycleway improvement



Trip naming terminology

The following trip naming is used in the discussion that follows:

- Existing trips: Trips 1 to $Q_{CWS,BC}$. They use the adjacent cycle lanes in the BC and the new cycleway segment in the PC
- New cycleway trips: Trips $Q_{CWS,BC}$+1 to $Q_{CWS,PC}$
- BC marginal trip: Trip $Q_{CWS,BC}$, the last trip drawn to using the cycleway segment in the BC
- PC marginal trip: Trip $Q_{CWS,PC}$, the last trip drawn to using the improved cycleway segment in the PC
- First new cycling trip (i.e. of the new trips, the one with the highest MWTP): Trip $Q_{CWS,BC}$+1 . In the BC this trip was almost drawn to using the cycleway, but its MWTP was just less than $GC_{CWS,BC}$. Any small reduction in GC_{CWS} would have caused it to switch. With the improvement, it will be the first to switch
- Last new cycling trip (i.e. of the new trips, the one with the lowest MWTP): Trip $Q_{CWS,PC}$ which is also the PC marginal trip. This trip would not have switched if the reduction in GC_{CWS} from the improvement had been fractionally smaller. It requires the full GC_{CWS} reduction to bring about the switch
- Intermediate trips: Other trips between the first and last new cycleway trips, i.e. trips $Q_{CWS,BC}$+2 to $Q_{CWS,PC}$–1.

A.1.5 User benefits from the cycleway improvement

Benefits per trip for key trips

The benefits arising from the improvement are as follows:[4]

- Existing trips: Each trip benefits by the full reduction in GC per trip ($GC_{CWS,BC}$ – $GC_{CWS,PC}$)
- The first new cycleway trip ($Q_{CWS,BC}$+1): The MWTP is just less than for trip $Q_{CWS,BC}$, so it receives a gain approaching, but just less than the full reduction in GC, ($GC_{CWS,PC}$ – $GC_{CWS,BC}$), i.e. almost 100% of the benefit to existing trips
- The last new cycleway trip ($Q_{CWS,PC}$): The MWTP is just more than $GC_{CWS,PC}$, so receives only a very small gain approaching zero.
- Intermediate trips ($Q_{CWS,BC}$+2 to $Q_{CWS,PC}$-1): The benefit for each trip is the vertical gap between the demand curve (MWTP) and $GC_{CWS,PC}$. For these trips, MWTP > $GC_{CWS,PC}$, resulting in a benefit for each trip of (MWTP – $GC_{CWS,PC}$) which is > 0. The size of the benefit per trip declines as we move down the demand curve from point A towards point B

Combined benefits across cycleway trips

Adding up the benefits per trip across all cycleway trips result in the following total benefits:

- Existing trips: Total benefit is the shaded area ACDE in Figure 6 between trips 1 to $Q_{CWS,BC}$
- New cycleway trips: Total benefit is the shaded area between $Q_{CWS,BC}$ and $Q_{CWS,PC}$ in Figure 6.

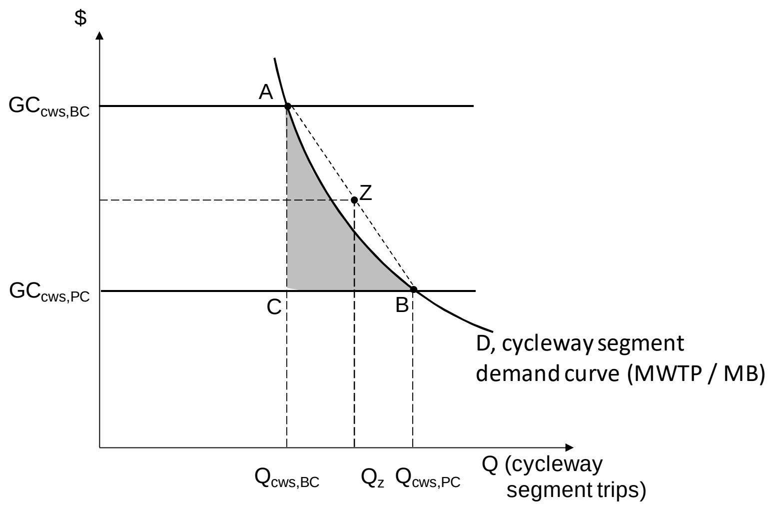
A.1.6 Rule-of-a-half approximation

Figure 7 shows a blow up of the part of the demand curve between $Q_{CWS,BC}$ and $Q_{CWS,PC}$. The *shaded area* shows the combined benefit summed across all new cycleway trips based on the above discussion. For each trip the benefit is the vertical gap between MWTP and $GC_{CWS,PC}$, and the shaded area is the sum of these vertical gaps across all new trips.

Note that the demand curve in Figure 7 is drawn as non-linear, the shape typically observed in practice. Measuring the shaded area in Figure 7 with a non-linear demand curve requires careful calculations for all the trips over this range.

[4] In ATAP T2, the economics terminology used to refer to the benefit to each trip is the increase in consumer surplus, where consumer surplus is the difference between MWTP and GC.

Figure 7: Benefits to new cycleway trips



A simpler more practical approach is to estimate the shaded benefit area in Figure 7 using an approximation called the 'rule-of-a-half'. It says that if we assume that the demand curve is linear between $Q_{CWS,BC}$ and $Q_{CWS,PC}$ (a straight line), the shaded area can be approximated by the area of the triangle ABC, i.e.

- total benefit to new cycleway trips = 50% of reduction in GC * number of new cycleway trips
- average benefit per new cycleway trip = 50% of reduction in GC, i.e. one half of the benefit gained by the existing trips.

Another way of saying this is: some new trips will benefit close to 100% of that of an existing trip; others will gain almost nothing; and across all new trips the average is 50%.

The rule-of-a-half approximation is generally considered to be a reasonable estimate of the benefit to the new cycleway trips provided the change in GC_{CWS} is not too large.

A.1.7 Benefit formulas summary

In summary, the standard approach discussed above results in the following benefit formulas:

Existing trips:

- Benefit per trip = $(GC_{CWS,BC} – GC_{CWS,PC})$
- Total benefit across all existing trips = $(GC_{CWS,BC} – GC_{CWS,PC}) * Q_{CWS,BC}$

New trips:

- Benefit per trip (half the benefit per trip of existing trips) = $0.5 * (GC_{CWS,BC} – GC_{CWS,PC})$
- Total benefit across all new trips = $0.5 * (GC_{CWS,BC} – GC_{CWS,PC}) * (Q_{CWS,PC} – Q_{CWS,BC})$

A.1.8 Worked example results

In the worked example, the initiative results in: reductions in cycling safety costs of $0.656 per trip and cycling time costs of $0.307 per trip (see section 8), with the overall reduction in GC being $0.963 (i.e. $0.656 + $0.307. Accordingly:

- Existing cycling trips benefit by: $0.963 per trip
- New cycling trips benefit on average by: $0.963 / 2 = $0.481 per trip

A.2 Benefits to new cycleway trips – breakdown of net gain into component gains, losses and trade-offs

We have explained above how the net gain to new cycleway trips is measured, culminating in the use of the 'rule-of-a-half' approximation. By definition, the net gain is also the sum of its component parts: gains and losses. This section provides a complementary discussion linking the net gain to new cycleway trips with the associated cost component gains and losses.

Section A.2.1 considers the gains and losses to new trips in generic terms, using the example of switching from car use. Sections A.2.2 to A.2.4 then illustrate those generic gains and losses with indicative quantifications for three key new cycleway trips as benchmarks: the first and last trips to switch in the PC, and an intermediate trip between these two.

A.2.1 Gains and losses from switching to the new cycleway segment

Consider the generic choice situation for a trip that switches from car to using the cycleway segment. Table 6 illustrates the situation for an indicative person, showing both gains and losses associated with switching from car to cycleway.

Table 6: Gains and losses of switching from car to cycleway

GC component	Gain	Loss	Change
SC (safety)	Car crash risk avoided	Cycling crash risk incurred	Safety gain because trip is less safe cycling than in car
TC (time)	Driving time avoided	Cycling time incurred	Loss assuming cycling takes longer
HCp (private health)	Private health benefit from physical activity		Private health gain
MC (money costs)	Car operating costs avoided (including parking)		Gain
OC (other costs – mode preference)		Prefers driving over cycling, so loses this preference	Loss of driving preference
	Overall gain, G = sum of component gains	Overall loss, L = sum of component losses	Net gain = G – L

The details within the Table 6 can vary from between people and trips. However, for the decision of whether to switch from car to cycleway we can make some general observations:

- Both gains and losses can be expected across different cost components

- The choice therefore involves trade-offs between these gains and losses
- Switching will only occur when it is beneficial to do so, that is when there is a net gain overall.

The same framework would also apply to consider switching from other modes (public transport, walking, etc) and newly generated trips. For the latter, the loss involves the forgone value of the activities undertaken prior to making the new cycleway trip.

A.2.2 First new cycleway trip in PC, $Q_{CWS,BC}+1$

As indicated in section A.1.4, in the BC this trip was almost drawn to using the cycleway, but its MWTP was just less than $GC_{CWS,BC}$. Any small reduction in GC_{CWS} would have caused it to switch. In the PC, with the improvement implemented, it is the first to switch.

Table 7 shows two sets of numbers for this trip: columns A to F show the cost per trip; and columns G and H show the resulting gains and losses if switching from car to cycleway were to occur. The net gain / loss from switching is shown at the bottom of columns G and H.

Table 7: Gains/losses in switching from car to cycleway – First new cycleway trip

	A	B	C	D	E	F	G	H
	Cost per trip						**Mode Switching**	
	In BC		**Project Impact**		**In PC**		**Gain(+) / Loss(-)**	
Perceived cost components	car	bike	car	bike	car	bike	In BC	In PC
a) Affected by initiative								
SC (safety cost)	$1.10	$4.95	$0.00	-$0.66	$1.10	$4.29	-$3.85	-$3.19
TC (time cost)	$1.88	$4.69	$0.00	-$0.31	$1.88	$4.38	-$2.81	-$2.50
b) Not affected by initiative								
HCp (private health cost)	$4.30	$0.00	$0.00	$0.00	$4.30	$0.00	$4.30	$4.30
MC (money cost – avoided car use costs (VOC, parking)	$2.85	$0.00	$0.00	$0.00	$2.85	$0.00	$2.85	$2.85
OC (other private costs – relative mode preference)	$0.00	$0.50	$0.00	$0.00	$0.00	$0.50	-$0.50	-$0.50
NET GAIN / LOSS FROM SWITCHING FROM CAR TO CYCLEWAY >>							**-0.01**	**0.95**

Table Notes:

- Costs are shown by cost component (rows)
- Columns A and B show costs in the BC for undertaking the trip by car or bike
- Columns C and D show the impact of the initiative. There is no impact on car costs, but a reduction in cycleway costs: safety (–$0.66) and time (–$0.31), for a total reduction of –$0.96
- Columns E combines columns A & C, and column F combines columns B & D, to produce PC costs
- Columns G and H show by cost component the gains (+) / losses (–) if switching from car to cycleway were to occur in the BC (hypothetically) and PC respectively. Column G is the difference between columns A and B. Column H is the difference between columns E and F
- Adding up the gains and losses in columns G and H respectively produces the NET GAIN / LOSS OF SWITCHING from car to cycleway in the BC and PC, shown at the bottom of the table.

Now consider the choices and outcomes in both the BC and PC associated with the option of switching from car to cycleway.

In the BC (before the initiative is implemented) (refer column G):

- The trip is made by car, so the option of switching to the cycleway when BC infrastructure is in place must involve a net loss in order to reflect the actual choice to travel by car
- The net loss for the switching option must be very small (–$0.01), approaching zero, reflecting the fact that only a small reduction in GC_{CWS} would be required to entice switching to the cycleway
- The switching option net loss is made up of both gains and losses across the cost components. The switching option would involve:
  - Losses in terms of safety costs (-$3.85), time costs (–$2.81) and other private costs (preference for driving, –$1.15)
  - Gains in terms of private health costs (+$4.45) and money cost (+$3.35)
- The switching gains just fail to offset the switching losses. The gains in private health and avoided operating cost are just not large enough to entice switching.

In the PC (after the initiative is implemented):

- The initiative reduces the time and crash costs of using the cycleway (columns B, D and F). This in turn reduces the safety and time switching losses (compare columns G and H: for safety reducing from –$3.85 to –$3.19; and for time reducing from –2.81 to –2.50). Switching gains / losses in the other GC components are not affected by the initiative — they are the same as in the BC (compare columns G and H)
- There is now an overall switching net gain of +$0.95, and switching from car to cycleway therefore occurs. The net gain is only a fraction less than, and almost 100% of, the total reduction in GC (–$0.96) reflecting the fact that only a small reduction in GC_{CWS} would have been sufficient to entice switching
- The switching net gain is made up both gains and losses:
  - Losses in terms of crash costs (now –$3.19), time costs (now –$2.50) and loss of driving preference (–$1.15)
  - Gains in terms of private health costs (+$4.45) and money cost (+$3.35)
- The switching gains now easily offset the switching losses.

A.2.3 Last new cycleway trip in PC, $Q_{CWS,PC}$

As discussed in section A.1.4, as the last trip in the PC drawn to switching to the cycleway, the MWTP is just more than $GC_{CWS,PC}$, so the trip receives only a very small net gain approaching zero.

Table 8 adopts the same format as Table 7, with the numbers altered to reflect the situation for this trip. The numbers shown represent a different person from Table 7 (although in principle the table could be constructed to represent a different trip by the same person as in Table 7). The car money costs are lower (e.g. a more fuel efficient car) and the preference for car travel is stronger ($0.50 vs $0.99).

Table 8: - Gains/losses in switching from car to cycleway – Last new cycleway trip

	A	B	C	D	E	F	G	H
	Cost per trip						Mode Switching	
	In BC		Project Impact		In PC		Gain(+) / Loss(-)	
Perceived cost components	car	bike	car	bike	car	bike	In BC	In PC
a) Affected by initiative								
SC (safety cost)	$1.10	$4.95	$0.00	-$0.66	$1.10	$4.29	-$3.85	-$3.19
TC (time cost)	$1.88	$4.69	$0.00	-$0.31	$1.88	$4.38	-$2.81	-$2.50
b) Not affected by initiative								
HCp (private health cost)	$4.30	$0.00	$0.00	$0.00	$4.30	$0.00	$4.30	$4.30
MC (money cost – avoided car use costs (VOC, parking)	$2.40	$0.00	$0.00	$0.00	$2.40	$0.00	$2.40	$2.40
OC (other private costs – relative mode preference)	$0.00	$0.99	$0.00	$0.00	$0.00	$0.99	-$0.99	-$0.99
NET GAIN / LOSS FROM SWITCHING FROM CAR TO CYCLEWAY >>							**-0.95**	**0.01**

In the BC (see column G):

- The option of switching to the cycleway when BC infrastructure is in place must involve a net loss in order to reflect the actual BC choice to travel by car
- Switching would make them clearly worse off, with a net loss of $0.95

In the PC (see column H):

- As in Table 7, the initiative reduces time and crash costs of cycling, reducing the associated switching losses
- There is now a switching net gain (+$0.01) so switching to the cycleway segment occurs
- As the last trip to switch, the switching net gain is very small approaching zero
- The switching net gain is made up of gains and losses in cost components, with the gains only just outweighing the losses

A.2.4 An intermediate new cycleway trip

The third benchmark trip to consider is an intermediate trip between the first and last switchers considered above. We consider here the midpoint trip between the first and last switchers, trip (Q_Z in Figure 7).

Table 9 shows for this trip the equivalent of Tables 7 and 8. The component costs have been varied to produce the required net gain midway between those for the first and last switching trips. – the money costs and mode preference loss are between the values for the first and last new trips.

Table 9: Gains/losses in switching from car to cycleway – Intermediate new cycleway trip

	A	B	C	D	E	F	G	H
	Cost per trip						Mode Switching	
	In BC		Project Impact		In PC		Gain(+) / Loss(-)	
Perceived cost components	car	bike	car	bike	car	bike	In BC	In PC
a) Affected by initiative								
SC (safety cost)	$1.10	$4.95	$0.00	-$0.66	$1.10	$4.29	-$3.85	-$3.19
TC (time cost)	$1.88	$4.69	$0.00	-$0.31	$1.88	$4.38	-$2.81	-$2.50
b) Not affected by initiative								
HCp (private health cost)	$4.30	$0.00	$0.00	$0.00	$4.30	$0.00	$4.30	$4.30
MC (money cost – avoided car use costs (VOC, parking)	$2.60	$0.00	$0.00	$0.00	$2.60	$0.00	$2.60	$2.60
OC (other private costs – relative mode preference)	$0.00	$0.72	$0.00	$0.00	$0.00	$0.72	-$0.72	-$0.72
NET GAIN / LOSS FROM SWITCHING FROM CAR TO CYCLEWAY >>							**-0.48**	**0.48**

In the BC (see column G):

- The option of switching must involve a net loss in order to reflect the actual choice to travel by car
- Switching would make them clearly worse off, with a net loss of $0.48

In the PC (see column H):

- The initiative reduces time and crash costs of cycling, reducing the associated switching losses
- There is now a switching net gain ($0.48) so switching to the cycleway segment occurs
- The switching net gain is made up of gains and losses in cost components, with the gains outweighing the losses, but not by as much as for the first trip to switch

A.3 Key observations

The construction of the missing cycleway segment in the worked example attracts new cycleway trips that switch to the cycleway from another mode or are newly generated trips. This appendix has provided supporting explanations for how benefits are calculated. The key observations are:

- The ‘rule-of-a-half’ method measures the *net* gain to new cycleway trips. It is therefore the correct measure to use in a cost-benefit analysis, which estimates net benefits (benefits minus costs).
- Making a new cycleway trips will involve both gains and losses across the various individual travel cost components (private health, vehicle operating costs, trip times, safety, loss of modal preferences). The decision to undertake a new cycleway trip involves trade-offs between the component gains and losses. Switching to a new cycleway trip only occurs if there is a *net* gain (as opposed to a net loss)
- By definition, the *net* gain is the sum of all the individual component gains and component losses. Estimation of the net gain to new cycling trips using the ‘rule-of-a-half’ therefore produces a comprehensive measure of overall benefit, with all component gains and losses taken into account
- Therefore, once net gains have been calculated using the ‘rule-of-a-half’, adding to the net gain estimate any individual component gains or losses leads to double-counting and an incorrect benefit estimate.

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