Smarter solutions

Multi-Criteria Analysis Tool – Technical Note

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Departmental approvals

Refer to the appropriate Risk Assessment Tool for relevant reviewer and approver

Date	Name	Position	Action required *(Review/endorse/approve)*	Due

Contents

Table of Figures

Table of Tables

1. Purpose

Multi-Criteria Assessment (MCA) is an assessment methodology used to select a preferred option, or hierarchise potential options, by evaluating the overall performance of short-listed options against a series of selected criteria. MCA forms an integral part of the Department of Transport and Main Roads' (TMR) project decision-making and investment process.

The ***Smarter solutions MCA Tool*** will provide decision-makers with a framework for undertaking MCA, ensuring that a consistent approach is applied and that the structure of decision problems effectively captures the benefits and impacts of low cost and non-infrastructure solutions. The key processes to be undertaken during MCA are outlined below:

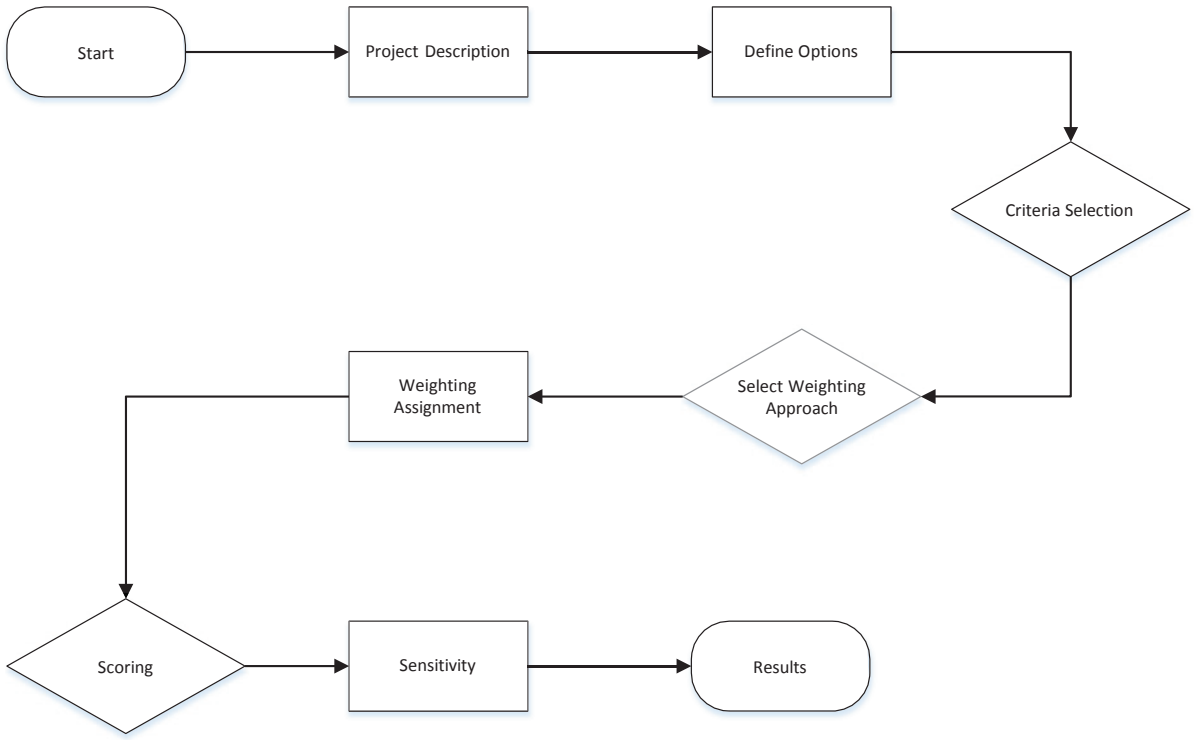

Figure 1 Smarter solutions MCA Tool overview

2. Project description

The project must be clearly defined within the MCA to ensure that appropriate options are short- listed for evaluation and that the criteria selected for assessment reflect the nature of the service requirement or opportunity. Accordingly, the project should be defined in terms of:

- Decision context - what is the overarching service need or opportunity that this project response seeks to address? What is the timeframe for required impacts?
- Network context – what is the current transport infrastructure environment? What is the age of current assets at project site? Is there any complimentary infrastructure investment occurring in close proximity within the transport network?
- Key objectives - what is the key objective the project is being implemented to achieve? What are the segmented objectives (ultimate, intermediate, immediate) and corresponding timeframes?

3. Define options

Following the initial identification and evaluation of potential project options during concept development, a refined short-list of viable options must be selected for inclusion in the MCA. Short-listed options must be clearly defined, at a minimum, in terms of the impacts, timeframes, benefits and costs. This facilitates the appropriate selection and assessment of options against the evaluation criteria.

Using the ***Smarter solutions – Reference Guide***, a network optimisation solution (NOS) option should be short-listed within this stage of the MCA. Understanding the appropriate application of an NOS, as a partial, whole or supporting solution, will guide this identification.

Note: The identification of potential options must include a Base Case, which is described as the 'do minimum' approach. This approach describes the changes that would be required to maintain the current transport environment across the evaluation period. While it is not necessary to describe the specific details of the Base Case within the MCA, it should be understood that the Base Case will include measures to address sensible increases in transport capacity to cater for the growing population and congestion problem. Preserving the conditions and characteristics of the current transport network facilitates a more robust comparison of relative options.

4. Criteria selection

Selecting appropriate and relevant criteria is a critical component of the MCA process. Criteria must accurately reflect the potential impact of all short-listed options and facilitate the appropriate evaluation and comparison of these alternative options in addressing the identified transport need/ service requirement. Within this MCA Tool a comprehensive range of criteria have been detailed for selection. This criteria has classified into 5 broad categories:

1. Economic Data
2. Transport Performance and Logistics
3. Construction and Constructability
4. Environmental Impact
5. Social Factors

When NOS are identified in the short-listed options, the following criteria must be selected.

- Implementation Cost
- Whole-of-Life Operating and Maintenance Costs
- Level of Service (LOS)
- Implementation Risk
- Value for money
- Performance horizon (benefitted years)
- Stageability
- Regional Development
- Rapid Benefit Cost Ratio

Criteria relating to intersection delay, public transport patronage and freight should also be selected where appropriate.

Details of each criteria, including method of measurement and scoring principals, are included in Appendix 2. Additional criteria can be added to the Excel Tool as required.

5. Weighting approach

There are various different preference weighting methodologies that can be utilised for assigning relative weighting to the criterion in multi-criteria assessment. The key objective in assigning weights is to determine the relative importance of the decision criteria (against other criteria under consideration) to the specific transport problem and/or project objective.

Four primary weighting techniques are included within this MCA Tool. These techniques can be categorised into two broad methodologies - ranking method and analytical hierarchy approach. Both weighting methodologies rely on the subjective judgements of decision-makers to determine priority rankings, before applying objective formulae to obtain normalised weightings.

Based on the mixed nature (qualitative and quantitative) of the MCA criteria, subjective ranking is required due to the difficulty experienced in eliciting relative weightings for decision criteria. This difficulty can be attributed to various factors including the qualitative nature of some criteria, lack of appropriate expertise, incomplete/partial information, stage in the investment decision making lifecycle, information processing capability and potential difficulty in reaching consensus among participants/stakeholders.

Accordingly, priority ranking is easier to elicit, however care must be taken to ensure that these rankings are not distorted by bias. It is further recommended that the ranking of options is facilitated in an open forum to eliminate this potential bias and to ensure that sufficient discussion and documentation can ensue to support decision-making.

5.1 Ranking method

Ranking methods derive weightings by applying a formula to the straight priority rank of the selected criterion. Because these methods are based on ordinal information about criteria, ranking methods are considered the easiest and most time efficient methods for assigning weightings. The three ranking methods included in this MCA Tool are:

5.1.1. Rank Sum

5.1.2. Rank Reciprocal

5.1.3. Rank Order Centroid

Ranking methods are recommended when there is a high level of information asymmetry, particularly for criteria that are qualitative in nature.

Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) is a well-developed method for ordering attributes or characteristics, and can be effectively used for weighting relative criterion in MCA. The following method of AHP is included in this MCA Tool:

5.1.4. Pairwise Comparison

AHP is not recommended when there is an exhaustive list of criterion, primarily due to the time- intensity of the pairwise comparison task.

Overall, the approach chosen to derive criterion weightings will strongly influence the final results of the MCA. The choice of weighting approach should be contingent on the level of information available to support the prioritisation of criteria, either through straight rank or pairwise comparison.

5.1.1 Rank sum

The rank sum weighting method assigns weightings by first ranking each criteria in order by preference; the most preferred option is selected as the first rank. The relative weightings are then calculated by applying the following formula to the ranked criterion.

$$wt_i = \frac{K - r_i + 1}{\sum_{j=1}^{K} K - r_j + 1}$$

Where:

- r_i is the rank of the *i*th objective
- K is the total number of objectives

Results summary

The rank sum methodology derives weightings that are more narrowly distributed relative to alternative ranking methodologies (see Appendix 1).

5.1.2 Rank reciprocal

The reciprocal (or inverse) weights method assigns weights by ranking each criteria in order by preference; the most preferred option is selected as the first rank. The relative weightings are then calculated by applying the following formula (which calculates the normalised reciprocal of each preference ranking) to the ranked criteria.

$$wt_i = \frac{1/r_i}{\sum_{j=1}^{K} (1/r_j)}$$

Where:

- r_i is the rank of the *i*th objective
- K is the total number of objectives

Results summary

The rank reciprocal methodology returns weights that are more dispersed than the rank sum methodology, with greater 'importance' placed on the first rank (see Appendix 1). This weighting distribution may be sought if a particular criteria addresses a specific requirement of the project need / opportunity.

5.1.3 Rank order centroid

The rank order centroid weighting method aims to minimise the maximum error of each weight by identifying the centroid of all possible weights relative to the assigned ranking of alternatives. Similar to the other rank methods, the criteria must first be ranked by preference before applying the following formula to elicit the weightings.

$$wt_i = \left(\frac{1}{K}\right)\sum_{j=1}^{K}\left(\frac{1}{r_j}\right)$$

$$wt_1 = \left(1+\frac{1}{2}+\frac{1}{3}+\ldots\frac{1}{K}\right)/K$$

$$wt_K = \left(0+0+0+\ldots\frac{1}{K}\right)/K$$

Where:

- r_j is the rank of the *j*th objective
- K is the total number of objectives

Results summary

Comparable to the rank reciprocal methodology, the rank order centroid methodology returns weights that are more dispersed than the rank sum methodology. However, rather than placing additional importance on the first rank only, rank order centroid exaggerates both the first and last ranked criterion (see Appendix 1). As above, the weighting method selected should reflect the relative importance of specific criteria to the project need / opportunity.

5.1.4 Pairwise

Pairwise comparisons allow decision makers to weight coefficients and compare alternatives with relative ease. As a process, the pairwise comparison technique involves comparing and prioritising each of the selected decision criteria against each other sequentially. For example, criterion A is compared against criterion B and assessed in terms of which criterion is ‘preferred’ over the other. This process results in a pair-wise matrix, as illustrated in Table 1 (over), and generates a series of weightings for each criterion.

Table 1 Pairwise scoring approach

	A	B	C	D	E	F	G	Occurrence +1	Weighting
A		B	A	A	E	F	A	4	14.2%
B			B	D	E	B	G	4	14.2%
C				C	E	C	C	4	14.2%
D					D	F	D	4	14.2%
E						F	G	4	14.2%
F							F	5	18%
G								3	11%
								28	100%

Results summary

The elicitation of pairwise ranking provides decision-makers with oversight into the relative degree of importance of each criterion with respect to each other. However, care must be taken as the nature and design of the pairwise comparison can result in logical flaws.

6. Weighting assignment

The weighting technique selected above will determine the method undertaken to assign weightings to the selected criteria. As mentioned, the selection of weighting technique should reflect the nature of the criteria selected to evaluate an options' suitability in satisfying a transport opportunity or service need.

This MCA Tool is designed to automate the assignment of weightings according to either the prioritised ranking of criteria or the pairwise comparison of criteria, depending on the weighting methodology selected.

7. Scoring

Each project option should be scored against each criteria according to the following five point scale:

Table 2 Smarter solutions MCA Tool scoring

Score	Scale	Description (unless otherwise specified in Appendix 2)
5	Very Positive	Option achieves a significantly better outcome than the Base Case.
4	Positive	Option achieves a better outcome than the Base Case.
3	Neutral	Option achieves an outcome equivalent to the Base Case.
2	Negative	Option achieves a poorer outcome than the Base Case.
1	Very Negative	Option achieves a significantly poorer outcome than the Base Case.

Note: The MCA Tool prepopulates the score for the Base Case option, which will equal 3 × nn, where nn equals the number of criteria selected. The Base Case score is important for project prioritisation and decision-making; options that score near or below the Base Case should be further evaluated to assess the viability of these options to deliver value for money and material improvements in network performance (or meet future service requirements).

The Base Case is defined in Section 4.

Further details regarding the explicit description of each scale rating to the criteria can be found in Appendix 2.

8. Sensitivity

A sensitivity analysis should be conducted in order to assess the robustness of the final ranking against the assigned criterion weights. Various methods of sensitivity testing can be applied to MCA; this Tool incorporates a form of 'thresholding'.

This sensitivity analysis approach assesses the robustness of selected options by changing the proportional weightings of each criteria by ±25% in the first instance and then by ±50%. This approach exposes the individual criteria that are most sensitive to changes in weighting and accordingly facilitates the narrowing of options to finalise the project decision.

9. Results

The results of the MCA, inclusive of the sensitivity analysis, must be assessed to determine which option is most suitable, within the defined MCA criteria, at addressing the identified service need / requirement.

Appendix 1: Weighting Methodology Comparison

The following table illustrates the different weighting allocation to criteria based on the selection of weighting methodology.

Table 3 Weighting methodology comparison

Criterion	Straight Rank	Rank Sum		Rank Reciprocal		Rand Order Centroid	
		Weight	Normalised Weight	Reciprocal Weight	Normalised Weight	Reciprocal Weight	Normalised Weight
A	4	2	13.3%	0.250	10.9%	0.250	9.0%
B	2	4	26.7%	0.500	21.9%	0.500	25.7%
C	5	1	6.7%	0.200	8.8%	0.200	4.0%
D	1	5	33.3%	1.000	43.8%	1.000	45.6%
E	3	3	20.0%	0.333	14.6%	0.333	15.7%
Total		15	100.0%	2.283	100.0%	2.283	100.0%

Appendix 2: Criteria for selection

Criterion	Indicator	Measure	Scoring Range				
			1	2	3	4	5
Economic Data							
Implementation Costs*	Estimated cost of construction and procurement (outturn estimate)	$	Estimated cost is significantly higher than NOS option (> $100 million more)	Estimated cost is moderately higher than NOS option ($0 - $100 million more)	Estimated cost is equivalent to the cost of the identified NOS option	Estimated cost is moderately less than NOS option ($0 - $100 million less)	Estimated cost is significantly less than NOS option (> $100 million less)
Whole-of-life Operation and Maintenance*	Estimated cost of whole-of-life asset operation and maintenance	$	Estimated cost is significantly higher than NOS option (> $100 million more)	Estimated cost is moderately higher than NOS option ($0 - $100 million more)	Estimated cost is equivalent to the cost of the identified NOS option	Estimated cost is moderately less than NOS option ($0 - $100 million less)	Estimated cost is significantly less than NOS option (> $100 million less)
End-to-end cost	Impact on direct end-to-end cost or price of travel (incl. amenity)	Descriptive	Significant negative impact on the direct end-to-end cost / price of travel (50% - 100% increase on Base Case)	Moderate negative impact on the direct end-to-end cost / price of travel (0% - 50% increase on Base Case)	No impact on the direct end-to-end cost / price of travel relative to Base Case	Moderate positive impact on the direct end-to-end cost / price of travel (0% - 50% reduction on Base Case)	Significant positive impact on the direct end-to-end cost / price of travel (50% - 100% reduction on Base Case)

Criterion	Indicator	Measure	Scoring Range				
			1	2	3	4	5
Road User Vehicle Operating Costs	Estimated change in vehicle operating costs (Vehicle/Bus operating costs: fuel, tyre wear, lubricants, repairs, maintenance)	$	Significant increase in vehicle operating costs (50% - 100% increase on Base Case)	Moderate increase in vehicle operating costs (0% - 50% increase on Base Case)	No change to vehicle operating costs relative to Base Case	Moderate reduction in vehicle operating cost (0% - 50% reduction on Base Case)	Significant reduction in vehicle operating cost (50% - 100% reduction on Base Case)
BCR	Rapid Benefit Cost Ratio	Ratio	0 to 0.5	0.5 to 1	N/A	1 to 1.5	> 1.5
Traffic Performance and Integration							
Network Connectivity	Impact on the directness of links and the density of connections in the network	Descriptive	Significant negative impact on network connectivity relative to Base Case	Moderate negative impact on network connectivity relative to Base Case	No impact on network connectivity relative to Base Case	Moderate positive impact on network connectivity relative to Base Case	Significant positive impact on network connectivity relative to Base Case
Operating Conditions	Change in the efficiency of operating conditions	Descriptive	Significant negative impact on operating conditions relative to Base Case	Moderate negative impact on operating conditions relative to Base Case	No impact on operating conditions relative to Base Case	Moderate positive impact on operating conditions relative to Base Case	Significant positive impact on operating conditions relative to Base Case

Criterion	Indicator	Measure	Scoring Range				
			1	2	3	4	5
Travel Time Reliability	Impact on time travel reliability, measured by the percent variation in travel time	Travel delay measured by actual travel time net average travel time	Travel delay equal to above 45% of average travel time	Travel delay equal to between 35% and 45% of average travel time	Travel delay equal to 35% of average travel time	Travel delay equal to between 25% to 35% of average travel time	Travel delay equal to less that 25% of average travel time
LOS	Impact on transport network performance as captured by the level of service rating	A-F LOS Scale	Significant negative impact on level of service relative to Base Case (-2 ratings)	Moderate negative impact on level of service relative to Base Case (-1 rating)	No change in level of service relative to Base Case	Moderate positive impact on level of service relative to Base Case (+1 rating)	Significant positive impact on level of service relative to Base Case (+2 ratings)
Intersection Delay	Change in intersection delay	min	Significant negative impact on intersection delay	Moderate negative impact on intersection delay	No impact on intersection delay relative to Base Case	Moderate positive impact on intersection delay	Significant positive impact on intersection delay
Public Transport Patronage	Change in user behaviour to increase public transport patronage	% of public transport mode share	Significant reduction in public transport patronage	Moderate reduction in public transport patronage	No impact on public transport patronage relative to Base Case	Moderate increase in public transport patronage	Significant increase in public transport patronage
Active transport	Impact on active transport users	Descriptive	Significant negative impact on active transport	Moderate negative impact on active transport	No impact on active transport relative to Base Case	Moderate positive impact active transport	Significant positive impact on active transport

Criterion	Indicator	Measure	Scoring Range				
			1	2	3	4	5
Performance Horizon	Performance of the option over time, as measured by the duration of benefits	Years	N/A	N/A	Duration of benefits < 5 years	Duration of benefits between 5 – 10 years	Duration of benefits > 10 years
Amenity of travel	Change in the perceived quality or amenity of travel	Descriptive	Significant negative impact on the perceived quality and amenity of transport network relative to Base Case	Moderate negative impact on the perceived quality and amenity of transport network relative to Base Case	No impact on the perceived quality and amenity of transport network relative to Base Case	Moderate positive impact on the perceived quality and amenity of transport network relative to Base Case	Significant positive impact on the perceived quality and amenity of transport network relative to Base Case
Safety							
Safety	Impact on safety incl. accidents, injuries, casualties and property damage	# crashes per million VKT	Significant negative impact on safety relative to Base Case	Moderate negative impact on safety relative to Base Case	No impact on safety relative to Base Case	Moderate positive impact on safety relative to Base Case	Significant positive impact on safety relative to Base Case
Freight							
Freight Volume	Impact on freight volume	m^3/pkt	Significant reduction in freight volume relative to Base Case	Moderate reduction in freight volume relative to Base Case	No change in freight volume relative to Base Case	Moderate increase in freight volume relative to Base Case	Significant increase in freight volume relative to Base Case

Criterion	Indicator	Measure	Scoring Range				
			1	2	3	4	5
Freight Vehicle Operating Costs	Estimated change in freight vehicle operating costs (Vehicle operating costs: fuel, tyre wear, lubricants, repairs, maintenance)	$	Significant increase in vehicle operating costs (50% - 100% increase relative to Base Case)	Moderate increase in vehicle operating costs (0% - 50% increase relative to Base Case)	No change to vehicle operating costs relative to Base Case	Moderate reduction in vehicle operating cost (0% - 50% reduction relative to Base Case)	Significant reduction in vehicle operating cost (50% - 100% reduction relative to Base Case)
Frequency of Service	Impact on the frequency of freight services	# (measured relative to Base Case)	Significant reduction in freight frequency relative to Base Case	Moderate reduction in freight frequency relative to Base Case	No change in freight frequency relative to Base Case	Moderate increase in freight frequency relative to Base Case	Significant increase in freight frequency relative to Base Case
Construction and Constructability							
Traffic Management	Impact on traffic management during construction / implementation	Descriptive	Significant negative impact on traffic management during construction / implementation	Moderate negative impact on traffic management during construction / implementation	No impact on traffic management during construction / implementation	Moderate positive impact on traffic management during construction / implementation	Significant positive impact on traffic management during construction / implementation
Community Disruption	Impact of construction on the local community, including visual amenity, safety risk, increased traffic and additional parking demand	Descriptive	Significant negative impact on local community	Moderate negative impact on local community	No impact on local community as a result of construction	N/A	N/A

Criterion	Indicator	Measure	Scoring Range				
			1	2	3	4	5
Engineering / Constructability	Potential engineering or construction challenges - during construction or across lifecycle	Descriptive	Significant evidence of potential engineering or construction challenges	Moderate evidence of potential engineering or construction challenges	No evidence of potential engineering or construction challenges	N/A	N/A
Geotechnical Risk	Level of risk attributed to the geotechnical conditions at construction site	Descriptive	Significant geotechnical risk	Moderate geotechnical risk	No geotechnical risk	N/A	N/A
Ease of Construction	Level of political and construction risk resulting in delays and disruptions during construction	Descriptive	Significant increase in construction and political risk	Moderate increase in construction and political risk	No change in construction and political risk	Moderate decrease in construction and political risk	Significant decrease in construction and political risk
Stageability	Ability for the option to be implemented in discrete stages over time	Binary	N/A	No ability for the option to be implemented in stages	N/A	Ability for the option to be implemented in stages	N/A
Environmental Impact							
Noise and Air Quality	Impact on noise and air quality	Descriptive	Significant reduction in noise and air quality relative to Base Case	Moderate reduction in noise and air quality relative to Base Case	No change in noise and air quality relative to Base Case	Moderate increase in noise and air quality relative to Base Case	Significant increase in noise and air quality relative to Base Case

Criterion	Indicator	Measure	Scoring Range				
			1	2	3	4	5
Vehicle Emissions	Impact on vehicle emissions	Descriptive	Significant increase in fuel emissions relative to Base Case	Moderate increase in fuel emissions relative to Base Case	No change in fuel emissions relative to Base Case	Moderate reduction in fuel emissions relative to Base Case	Significant reduction in fuel emissions relative to Base Case
Flora and fauna	Impact on vegetation and / or sites of environmental importance	Descriptive	Significant negative impact on vegetation and / or sites of environmental importance relative to Base Case	Moderate negative impact on vegetation and / or sites of environmental importance relative to Base Case	No impact on vegetation and / or sites of environmental importance relative to Base Case	Moderate positive impact on vegetation and / or sites of environmental importance relative to Base Case	Significant positive impact on vegetation or sites of environmental importance relative to Base Case
Social Factors							
Land Use & Development							
Barriers to development	Are there any significant barriers to development? E.g. existing land use or cultural significance	Descriptive	Significant barriers to implementation arising from existing land use relative to Base Case	Moderate barriers to implementation arising from existing land us relative to Base Case e	No barriers to implementation arising from existing land use relative to Base Case	N/A	N/A
Future land use	Degree of alignment to strategic land use and planning objectives	Descriptive	Significant misalignment of option to strategic land use and planning objectives	Moderate misalignment of option to strategic land use and planning objectives	No change to future land use relative to Base Case	Well aligned to strategic land use and planning objectives	Perfectly aligned to strategic land use and planning objectives

Criterion	Indicator	Measure	Scoring Range				
			1	2	3	4	5
Socioeconomic							
Mode Shift	Impact on user behaviour and influence on mode shift	Descriptive	Significant negative impact on user behaviour and mode shift and mode shift relative to Base Case	Moderate negative impact on user behaviour and mode shift relative to Base Case	No impact on user behaviour and mode shift relative to Base Case	Moderate positive impact on user behaviour and mode shift relative to Base Case	Significant positive impact on user behaviour and mode shift relative to Base Case
Impact on property owners	Impact to local land, property and businesses resulting from disruption during construction and operation	Quantity of affected properties	Additional properties affected relative to Base Case – impact across a corridor/route spatial area	Additional properties affected relative to Base Case – impact across a localised spatial area	N/A	N/A	No addition properties affected relative to Base Case
Visual Amenity and Urban Quality	Impact on visual amenity and urban quality as a result of changes in bikeways, walking paths, noise during construction and design/aesthetic	Descriptive	Significant reduction in visual amenity and urban quality	Moderate reduction in visual amenity and urban quality	No impact on visual amenity and urban quality relative to Base Case	Moderate increase in visual amenity and urban quality	Significant increase in visual amenity and urban quality
Severance	Impact on community severance	Descriptive	Significant increase in community severence	Moderate increase in community severence	No impact on community severance relative to Base Case	Moderate reduction in community severence	Significant reduction in community severence

Criterion	Indicator	Measure	Scoring Range				
			1	2	3	4	5
Regional development	Change in the economic and social impact of the transport system on regional development	Descriptive	Significant negative impact on future regional development	Moderate negative impact on future regional development	No impact on future regional development relative to Base Case	Moderate positive impact on future regional development	Significant positive impact on future regional development

* Where an NOS option has not been short-listed for assessment, please refine these criteria to reflect the options identified and the key project objectives.