13 Stakeholder-Based Assessment

Multiple Criteria Analysis for Designing Cycle Routes for Different Target Populations

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CONTENTS

13.1 INTRODUCTION

13.1.1 RESEARCH SCOPE

Potential cyclists, beginner cyclists, utility cyclists, recreationalists and trail riders – similar categories have been defined as target populations by cycle programmes worldwide. This study refers to 'target populations' as those groups of people that have been defined by local, regional or national policy for specific cycling programme interventions. Europe's PRESTO Programme (Urbanczyk, 2010) explains the concept of target populations as part of their suggested marketing strategy for segmentation and targeting of different cycling groups. Partners of the PRESTO Programme believe a systematic application of infrastructural design and marketing will provide socially positive behavioural change through cycling programmes. This idea is not just applicable in Europe. As Damant-Sirois et al. (2014) discovered in Montreal, 'Cyclists react heterogeneously to interventions and infrastructure. Building a network adapted to different cyclist types and emphasizing its convenience, flexibility and speed could be an effective strategy for increasing cycling-mode share and frequency among the various groups'. Thus, a methodology that incorporates pre-construction assessment must be presented that accounts for the presence of these different groups. There are a number of existing assessment systems, such as the bicycle level of service (BLOS) assessment (Landis et al., 2003) and traditional transport multiple criteria analyses (MCAs) (Thomopoulos and Grant-Muller, 2012; Yang and Regan, 2012). Yet these assessments are not well developed for cycling programmes that need a systematic process to support decision-making.

Different countries are likely to define different target populations based on local travel behaviour (Kroesen and Handy, 2013) and the objectives of regional transport bodies (Thomopoulos and Grant-Muller, 2012). Similarly, route design criteria affecting a target population's safety and perception of the cycling environment will differ according to the city's situation. The objective of the research we describe in this chapter was, therefore, to create a methodology that can account for these sorts of variations. The methodology must be flexible enough for local engineers and designers to choose their own design-criteria hierarchy. It must also provide detailed segment and junction information when high resolution results are needed, but it must also be scalable and allow comparison with assessments of any of the city's other routes.

With these concerns in mind, in this chapter we present a methodology based on multiple criteria analysis (MCA) for the design of cycle routes that take into account any given city's target populations and their preferences. After the study area is introduced, the methods section covers six steps from defining criteria for stakeholder participation, performance measurements, standardised criteria performance scores, aggregated group ranks and a sensitivity analysis. The analysis section displays this methodology in practice at the study area in Christchurch, New Zealand. The chapter concludes with improvements for future work.

13.1.2 Study Area

BOX 13.1 Case Study Area

Christchurch is a major city on New Zealand's south island and has a population of 360,000 people. It is rebuilding its infrastructure after the 2010 and 2011 earthquakes that destroyed major parts of the city; this includes the development of an extensive cycleway programme. The building of cycling infrastructure is seen as a way to promote cycling, in particular for major groups such as school-going children and people who currently commute to work by car. The development of such public infrastructure is accompanied by all kinds of spatial decision-making problems such as which locations and communities to serve, which routes to develop, which designs to apply in which environments and so on. These problems are inherently complex due to physical limitations, finite resources, involvement of a number of parties and their mixed interests. For this reason, decision-makers use policy-driven and objective-based criteria to evaluate options, such as route alternatives, to help them compare and prioritise projects that are most suitable to their needs.

In 2014, the cycle programme manager for the city of Christchurch (New Zealand) requested that research be done on the use of multiple criteria analysis (MCA) for cycle route design. The city of

Christchurch (population 360,000) suffered a series of earthquakes in 2010 and 2011 that destroyed large parts of its infrastructure, which it is still in the process of rebuilding. The city has placed importance on improving its cycle network, with a total of NZD 156 million (approx. €90 million) to be allocated over a period of seven years, NZD 65 million of which was to be spent over a period three years on its 13 main routes (Christchurch City Council, 2016). The cycle network is meant to safely connect the city centre of Christchurch with major suburbs and activity centres. In this manner, the council intends to facilitate commuting by bicycle, as well encouraging cycling to school and for leisure activities and shopping trips.

Christchurch and many other cities in New Zealand want to encourage more people to take up cycling, mainly through educational programmes and infrastructural investment (Canterbury Regional Transport Committee, 2012). In Christchurch, about 7% of commuting trips and 3% of all trips are made by cycle (Butler, 2015). Unfortunately, there is no national framework for legally regulating efforts for the planning, design and implementation of bicycle facilities, although the New Zealand government recently injected NZD 330 million into a three-year Urban Cycleway Program (NZ Transport Agency, 2016). The quality of regional cycling projects is dependent upon the experience and judgement of locally available experts; national planning and design guidance is just now being prepared or updated.

The goals and road designs of these regional cycling projects are based on universally accepted supply-side criteria, yet provision of these infrastructure standards may not be enough to significantly increase a city's cycling modal share. As the current New Zealand national cycle network and route planning guide states, 'A perennial problem in cycle route network planning is the reliance on bright ideas and pet projects that may not have been critically evaluated for usefulness and value for money'. Similar to any other publicly funded infrastructural project, cycling routes should undergo assessment and review before being finalised (Land Transport Safety Authority, 2004). The Cycleway Program Manager and the lead Senior Traffic Engineer for Christchurch suggested that MCA be used to assess a section of the Norwest Arc, an 8 km planned orbital bicycle route that city designers had previously identified in an ad-hoc manner. A study area was chosen (see Figure 13.1) along this planned route to include two simple route options for assessment.

13.2 METHODOLOGY

BOX 13.2 Methods Applied in the Chapter

The methodology we developed in this case study is based on multi criteria analysis (MCA) techniques that have been modified to the problem of infrastructure appraisal and route selection. Based on focus group discussions, criteria were identified that were important for route quality. These main criteria were subdivided into 17 sub-criteria. Both main and sub-criteria were weighted on the basis of ranks that had been derived for the three main stakeholder groups identified: parents of school-going children; commuter cyclists; and potential cyclists. As a result, scores for two simple route options were calculated. The GIS-based approach allows for the analysis and visualization of individual route segments and junctions. For each route, this is broken down into their sub-criteria scores, overall route (total) scores and how these routes scores might be weighted to reflect a particular stakeholder perspective.

This section first describes the traditional MCA approach and then shows how it can be modified and improved for application to cycle route design. Figure 13.2 summarises the six steps used in this MCA study.

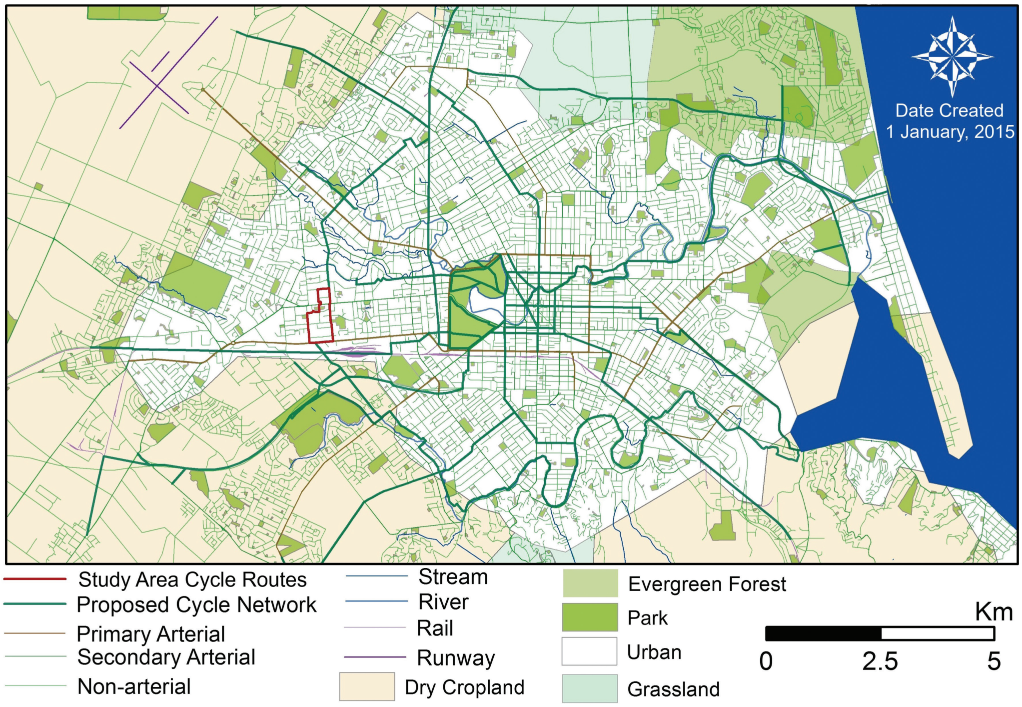


FIGURE 13.1 Map of study area in Christchurch and its surrounding areas.

13.2.1 Traditional MCA Methods

MCA's strength lies in its vast base of different industry users and the variety of applications developed by these users. The largest benefit of MCA is its ability to provide a structured government decision-making process in the face of conflicting criteria and stakeholder priorities. Value-focused and not alternative-focused, MCAs allow flexibility so criteria can be removed or altered and

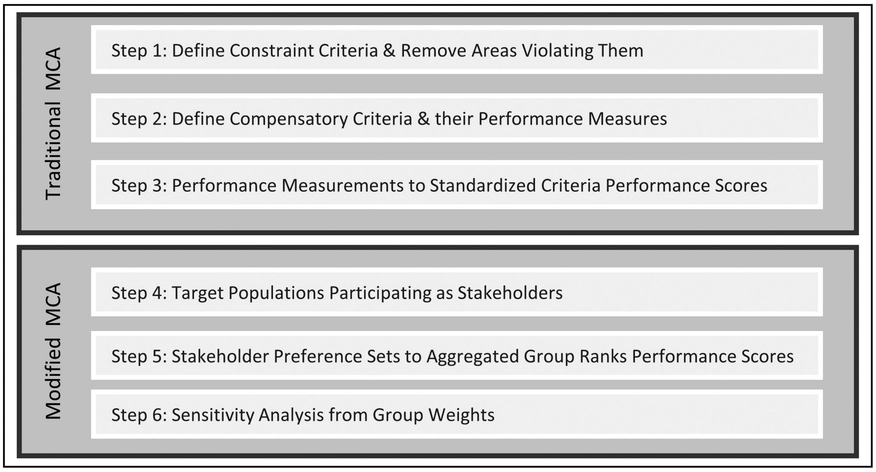


FIGURE 13.2 Steps in traditional and modified multiple criteria analysis (MCA).

preference sets can be assessed (Sharifi et al., 2006). Then, through performance measurement, standardization and weighting (of the multiple criteria according to their relative importance in a particular person's preference set), a variety of options can be analysed and compared to find which is the most suitable for each stakeholder group and their related policy visions or managerial objectives (Keshkamat et al., 2009; Sharifi, 2004).

13.2.1.1 Step 1: Define Constraint Criteria and Remove Areas Violating Them

Constraints are criteria or variables that are non-compensatory, or under conditions of strict dominance, and have the potential to cancel out the usefulness of the other criteria being assessed (Hajkowicz and Higgins, 2008; Pomerol and Barba-Romero, 2000), and as such can be included in thresholds via value functions but cannot be ranked. All domination options should be spatially excluded from a rank-based decision set before MCA is applied.

In the case of cycle route design, constraint criteria are especially important if running an MCA over a large area that has many roadway options. This is because constraints cannot be scaled or compared against other design criteria, and areas where they prevail must be removed from the spatial route options. Designers and engineers of cycle infrastructure must decide what the constraints of their city would be. If local designers or engineers believe any section of roadway is too hazardous or too expensive to provide bicycle-friendly infrastructure, then it is under the influence of an unavoidable and prohibitive constraint. Once defined, constraint criteria will eliminate some of the possible planned-route locations. Depending on local concerns, there can be any number of these constraint criteria. Throughout the rest of this chapter, these will be referred to as 'constraints', and any further mention of 'criteria' will solely refer to those criteria that are compensatory.

13.2.1.2 Step 2: Define Compensatory Criteria and Their Performance Measures

Unlike constraints, compensatory criteria are not prohibitive and have (to some extent) advantages and disadvantages. Compensatory criteria can be scored and ranked. These compensatory criteria are a standard of judgment or rule on the basis of which alternative decisions can be evaluated and ordered according to their desirability (Malczewski, 2006). Once compensatory criteria are defined, then a performance measure must be defined for each. Performance measures are indicators, a decision-option's raw score against a criterion (Hajkowicz and Higgins, 2008). Performance measures generally have units of measure.

For cycle route design, compensatory criteria can be based on international best practices and recent discoveries in the literature, but ultimately those local designers and engineers who will be using the output information must, in consultation with stakeholders, decide which criteria are most deterministic for the bicycle-friendliness of their city. Compensatory design criteria should then be given meaningful performance measures that can deal with the variation present within the city landscape. Examples of criteria might be 'slope' or 'outdoor attractiveness', with potential performance measures being 'average gradient per kilometre' or 'percentage vegetation land cover adjacent to road'. This value-based MCA allows different criteria and different performance measures to be input.

The process is the same regardless of which criteria or performance measures are used. After determination of the criteria scores, a total route suitability score can be calculated. This total score can be calculated in one of two ways: with, or without, compensating for the length of the segment. With compensation, each performance measure's scores are normalised on a scale from 0–1 and assigned to the segment or junction. The total route score is then a summation of all segment and junction scores divided by the sum of the number of segments and junctions. Without compensation, the scores of segments are normalised based on their length, then normalised on a scale from 0–1.

13.2.1.3 Step 3: Performance Measurements to Standardised Criteria-Performance Scores

To be comparable to each other, performance measures must be standardised into unitless scales. Linear maximum standardization is favoured among participatory suitability studies because it is easy to understand for stakeholders and it does not cause undue exaggeration between small measurement differences. Such small differences may be of only minor importance and may even be the result of measurement or estimation error. Equations 1a and 1b are common in linear maximum standardization practice in value-based MCAs, as demonstrated by Geneletti (2010) and others. This criteria standardization will result with criterion scores from ranging from 0–1.

$$\text{Standardized Cost Subcriterion Performance Score} = 1 - \left(\frac{\text{actual score}}{\text{maximum score}}\right) \tag{13.1a}$$

$$\text{Standardized Benefit Subcriterion Performance Score} = \left(\frac{\text{actual score}}{\text{maximum score}}\right) \tag{13.1b}$$

To be implemented in detailed cycle route design, this third step assumes the data for each data set of performance measures are available, clean and ready to use, and that all criteria performance measures have given their unstandardised score for each segment and junction. It also assumes each performance measure's score is either beneficial (positive) or detrimental (negative) to the overall bicycle-friendliness of the road segment and junction. Once these assumptions are fulfilled, they must be transformed into unitless scales with either Equation 1a or Equation 1b. To determine a total route suitability score, this standardization must be done for each segment and junction's performance measures. This preservation of detailed information is unused by most value-based MCAs, but it will allow useful information to be given to the cycle route designers, as can be seen in Figures 13.5 through 13.7. Information at the segment and junction level is also the key for any researchers who in the future would like to run MCA cycle route design assessments on an entire network.

13.2.2 Modifying MCA for Cycle Route Design

Above, Section 13.2.1 describes the beginning three steps traditionally followed in MCA. In this section we modify this traditional method in a further three steps (Steps 4–6) to make the MCA suitable for use in cycling infrastructure design. To our knowledge, these steps have never been used in MCA or by the cycling infrastructure design community.

13.2.2.1 Step 4: Target Populations Participating as Stakeholders

This MCA for cycle route design requires target populations to be defined by local cycle programme managers. These will probably be based on past cycling surveys, traffic counts and travel behaviour studies. However, policy-defined target populations are not always based on groups with homogeneous travel behaviour. Known heterogeneous populations should be handled with current best statistical practices.

Defining target populations enables focused research and engagement. Representative samples of each target population can be invited to participate in the design process as stakeholders. This stakeholder participation could take the form of survey campaigns, focus groups, web-based discussion and forums. The purpose of this participation is to: (1) present each participant with the design criteria set(s) and receive in return their ranking, stating their personal preferences; and (2) receive participants' feedback on past cycle route designs and concerns about upcoming plans. This additional information can also be a mechanism for target populations to state their post-construction satisfaction about certain facility designs. The method presented here (see Figure 13.3) suggests that setting a schedule to periodically seek people's comments on past projects (successes and failures)

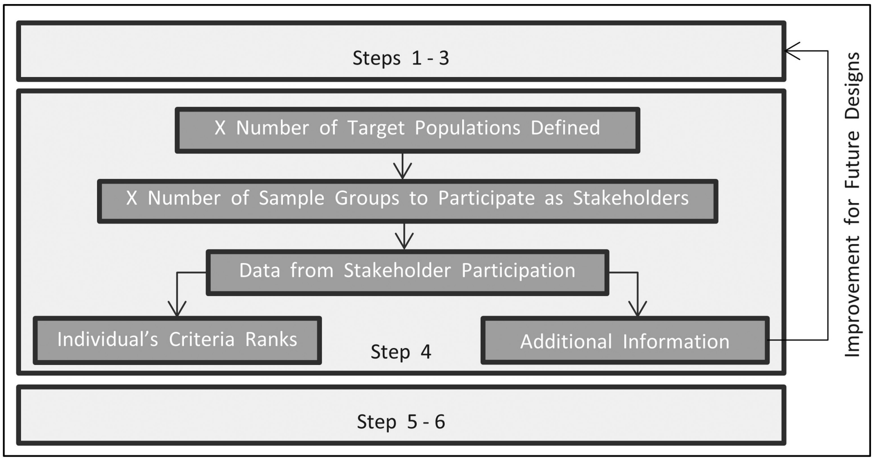
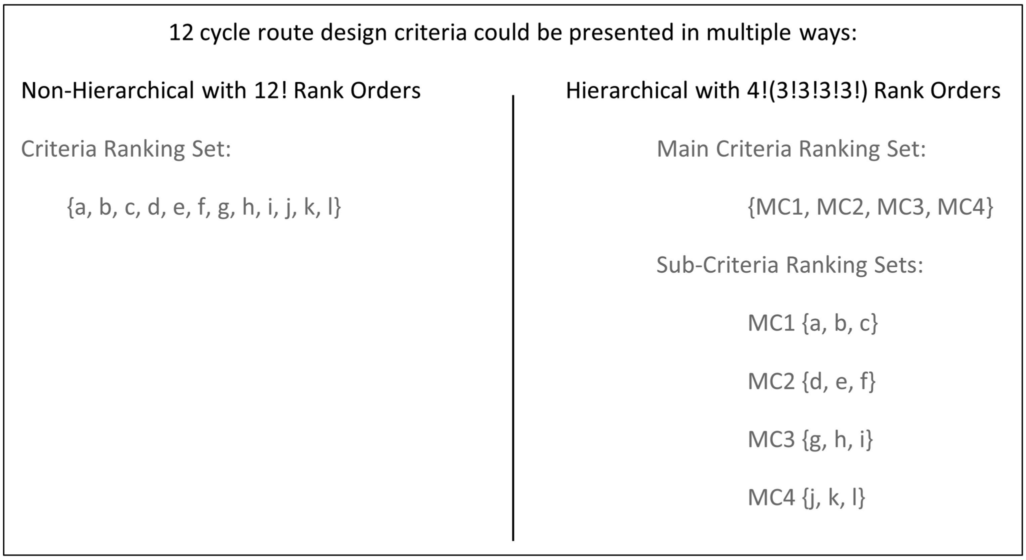


FIGURE 13.3 Target populations participating as stakeholders.

can help to regularly update the pre-construction design process and hopefully improve future cycle route designs.

Criteria can be presented to stakeholders for ranking in two main ways: hierarchically and non-hierarchically. There is a trade-off between a large number of criteria and more manageable assessments with a small number of criteria. An MCA with more design criteria allows for more specific answers, but it also allows greater variation between each two individuals' stated preference sets. If a large number of design criteria were chosen, then a hierarchical presentation should be chosen. Presentation of criteria matters to the reliability of the ranking results. With poorly presented criteria it will be hard to find useful results as every participant could give a drastically different ranking set. See the example in Figure 13.4, which has 12 arbitrary cycle-route criteria {a…l}.

Giving a participant/stakeholder a non-hierarchical set of 12 design criteria would allow the participant a total of 12! (i.e. 47,900,160) possible ranking alternatives (see Figure 13.4). This can


12 cycle route design criteria could be presented in multiple ways:

Non-Hierarchical with 12! Rank Orders

Criteria Ranking Set:

{a, b, c, d, e, f, g, h, i, j, k, l}

Hierarchical with 4!(3!3!3!3!) Rank Orders

Main Criteria Ranking Set:

{MC1, MC2, MC3, MC4}

Sub-Criteria Ranking Sets:

MC1 {a, b, c}

MC2 {d, e, f}

MC3 {g, h, i}

MC4 {j, k, l}

FIGURE 13.4 Cycle route design criteria organised in non-hierarchical and hierarchical ranking sets.

be dramatically reduced when the rankings are presented hierarchically. Splitting these criteria into three groups of main criteria, each with four sub-criteria, reduces the participant's possible ranking alternatives to 3!(4!4!4!) (i.e. 82,944). Even better, if these criteria are divided into four groups of main criteria, each with three sub-criteria, then each participant's possible ranking alternatives are reduced to 4!(3!3!3!3!) (i.e. 31,104, as shown in Figure 13.4).

There are an infinite number of possible design criteria sets, so there is not an optimal hierarchy. The presentation must be left to the judgment of the designers and engineers who choose the criteria. Theoretically, criteria's hierarchical presentation and the subsequent fewer ranking alternatives will reduce the possibility for variability of the answers. This is highly important considering each target cyclist population that is being sampled will probably display at least some heterogeneity of personal preferences. To properly sample these populations would already require a fairly large sample size and various recruitment sources. Thankfully, the necessary sample size for robust results is likely to be lower as the total possible ranking alternatives are diminished. Sample sizes for the participation of target cycling populations is beyond the scope of this chapter, but it certainly would be an interesting topic for future research.

13.2.2.2 Step 5: Stakeholder Preference Sets to Aggregated Group Ranks

Most traditional MCAs do not use group preferences; instead, each person's preference ranking is turned into their personal weighting scheme. These traditional MCAs are impossible when including the public in the design process. See Equation 2, modified from the MCA work of Mendoza and Martins (2006), who talk about the three methods for heterogeneous group opinions (fuzzy situations). If a city's cycle programme wants to avoid extremely pessimistic and extremely optimistic data transformations, the compromising midpoint should be chosen. Furthermore, when results show skewed distributions of criteria, then caution would dictate use of the median. Median criteria ranking sets of the three target cyclist groups can then be transformed into weights with the following equation:

$$W_i = \frac{R_i}{\sum R_i} \tag{13.2}$$

where:

W_i = the weight assigned to the criterion i;
R_i = aggregated target cyclist group rank to the criterion i.

Once the weights are aggregated for each target cyclist group, they can be multiplied by their respective standardised criteria scores. MCA's traditional weighted summation equation (Geneletti, 2010; Hajkowicz and Higgins, 2008; Pomerol and Barba-Romero, 2000) can be modified, as shown in Equation 3, to combine the scores into a single-route suitability score. This adapted version allows for the same sub-criteria to appear many times within the route (e.g. an individual visibility score for each junction along the route) without averaging. This is important. In order to prioritise design interventions, any route options must be addressed not only by their total suitability scores but also by the detailed performance of the road junctions and segments forming them. A bicycle route assessment providing only one final score is of very little use to designers and engineers. This approach, however, allows each segment and junction to maintain its broken-down scores before being included in the actual route sum. This actual route sum is then divided by the total possible route sum.

$$S = \frac{\text{actual route sum} \sum_{i=1}^{n} W_i X_i}{\text{total max route sum} \sum_{i=1}^{n} W_i \max X_\mathrm{i}} \quad \left(i = 1, 2 \ldots n\right) \tag{13.3}$$

where:

$$\sum_{i=1}^{n} W_i = 10 < W_i \leq 1$$

S = total route suitability score;
n = number of criteria;
W_i = weight assigned to the criterion i;
X_i = normalised score of criterion i.

13.2.2.3 Step 6: Sensitivity Analysis for Group Weights

A traditional MCA sensitivity analysis as seen in Geneletti (2010) changes weights at equal intervals to see if there is a reversal point in which an option scores as the 'best'. This would typically indicate how robust the scores were when under the influence of possible preferences of different decision-makers.

For the design of cycle routes, a similar but different sensitivity analysis could reference how each of the changing weights from each participating target cycling group changed the scores. This could be done for each junction and segment but is also summarised by the total route suitability score. If there is a change in the most suitable route option for different participating target cycling groups, then this signals a reversal point. Reversal points in cycle route design are interesting because they may highlight a route's relative weakness for a particular target population. If design interventions were made for the weakest point of this route, then the reversal point may disappear and the route's interventions could be assumed to be more robust for more target populations. This could benefit the design process of a cycle route that was currently facing public opposition.

13.3 APPLICATION OF MCA FOR CYCLE ROUTE DESIGN IN CHRISTCHURCH

Steps 1 and 2 are context dependent and the final design criteria must be accepted by the route designers who will be using the analysis results. Christchurch officials decided not to have constraint criteria create 'black spots' or 'no-go zones' for planned cycle routes. They wanted to emphasise the use of compensatory design criteria.

In the case of Christchurch's urban cycle routes, 49 design criteria were considered. These were narrowed down to 17 after being reviewed against both the cycling research literature and the city's needs. Table 13.1 below shows the seven main criteria and 17 sub-criteria and their performance measures in the hierarchy that was approved by city authorities. The hierarchy did not affect the equal-weight standardised criteria scores shown in Figures 13.5 through 13.7 (which are based solely on roadway performance measures); it only affected the scores weighted by the target cycling participants, as shown in Figures 13.8 and 13.9.

Christchurch's chosen criteria took into account both infrastructure supply and social demands. The city is situated in a temperate zone, predominantly on a flat sprawling plain, with the sea to its east and hills to its south. If the study area had been situated in a city with complex terrain or extreme environmental conditions, then the design criteria would have probably included characteristics such as steep slopes, road areas prone to ice accumulation etc. The methods we describe in this chapter are able to deal with whatever design criteria a local city would like to choose.

Some data were not available and were unable to be measured during our fieldwork due to lack of time and equipment. These proxies are listed in Table 13.1. Table 13.2 shows the data sets and how they were obtained. Most city representatives were associated with the CCC (Christchurch City Council), or the UC (University of Canterbury).

Once data is collected, Step 3 transforms the criteria performance scores into route suitability scores. The performance measures were computed for their respective road segments and junctions in ArcGIS ™ attribute tables. The raw data shows there are variations present in the micro-environments

TABLE 13.1
Chosen Criteria Hierarchy and Performance Measures (Acoustic Engineering Services, 2009; Christchurch City Council, 2014; Landis et al., 2003; Landis et al., 1997)

Main Criteria	Sub-Criteria (Segment or Junction) Data for Test Area)	Performance Measure Computed As
Comfort	S1_Non-slip surface (segment surface material chip size)	Chip size as proxy for macro-texture skid resistance
	S2_Roughness (average per road segment)	Link NAASRA Average = ((sum (tilt counts/20 metres)) / number of NAASRA measures per link)
Junction safety	J1_Visibility (junction average metres to potential obstruction)	Average visibility = ((sum of distances to surrounding properties) / number of surrounding properties)
	J2_Speed & Volume (junction speed as km/h & volume as 24-hour, four-day average ADT)	Speed × volume
	J3_Facility Capability (junction average reserve width)	Average Reserve Width = (Sum of roadway reserve widths) / number of roads at junction
Road capacity	S3_Effective width (segment width relative to 24-hour, four-day average ADT)	*Wv* = Effective width as a function of traffic volume *W*t = Total pavement width of shoulder and outside lane Wv = Wt if ADT > 4000 vehicles/day Wv = Wt (2-.00025 × ADT) if ADT ≤ 4000 veh/day and if the carriageway is unstriped and undivided Adopted from: (Landis, Vattikuti, & Brannick, 1997)
	S4_Traffic Composition (Segment % non-light vehicles)	% medium and heavy vehicles (categorized by weight and specified by RAMM definitions)
Directness & efficiency	S5_detour factor (DF segment × DF route)	Segment detour score = (link length / optimal link length) × (route length / optimal route length)
	J_4_Right-hand turns (junction turn count)	Sum turn counts for both directions
	J5_Delay (seconds average per junction)	Average delay = ((sum of the junction's delays along the route directions) / number of directional delays)
Connectivity & Transit Cohesion	S6_Connectivity (segment length)	Measured from cyclable cross-street to cyclable cross-street (unnamed residential and commercial cul-de- sacs)
	S7_Bus stops (# within 100 m network distance of segment ends	Count of bus stops within 100 m of road segment
Attractiveness	S8_Art/Parks/Public Areas (segment % frontage)	% public frontage = metres of public frontage along route link / total metres of route link
	J6_Noise & pollution (junction estimated noise as dBA Leq/day & volume of vehicles which expose cyclists to more PM10 estimated as vehicles/day) N	Intensity of noise & pollution emitting vehicles = (24-hour dBA Leq within 10 m) × ((24-hour ADT) × (% heavy emitting vehicles)) Adopted from: the (Acoustic Engineering Services, 2009) report completed for Christchurch City Council
	S9_Street lighting	Link lighting = no. of street lights along link / ((Total Carriageway Width) × (Route Link Length))
Trip generators & attractors	S10_Population adjacent to segment	Population adjacent to link = (No. dwellings adjacent to link) × (average household size) / (Route link length) Adopted from: Christchurch City Council (2014a), which reported an average 2013 household size of 2.5 people per dwelling, and the bicycle Latent Demand Score (Landis et al., 1997).
	S11_Destinations adjacent to segment	Destination adjacent to link = number of non-residential destinations with direct access to link / (Route Link Length) Adopted from: the bicycle Latent Demand Score (Landis et al., 1997), which uses attractions such as employments, shopping centres, parks, and schools.

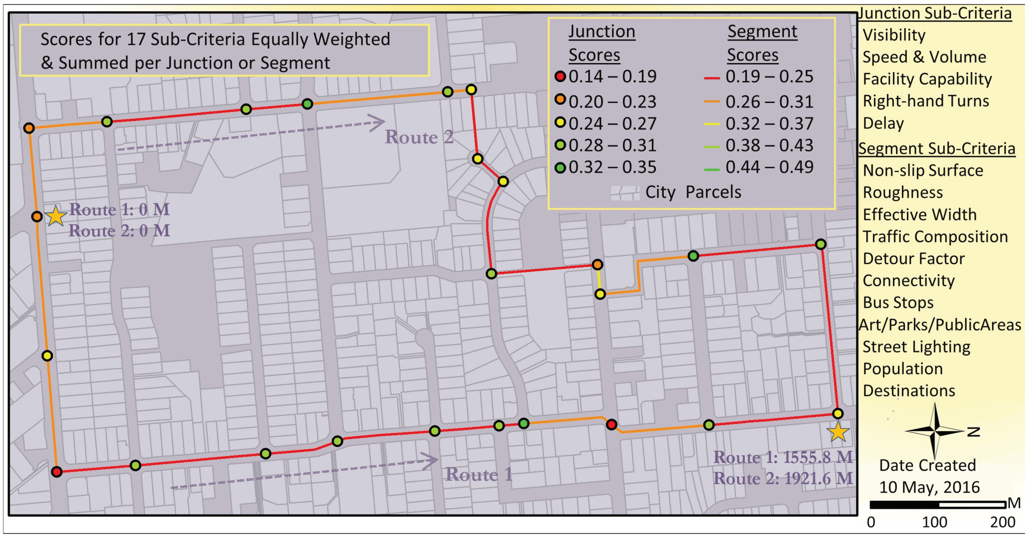


FIGURE 13.5 Map of route segment and junction scores when equally weighted.

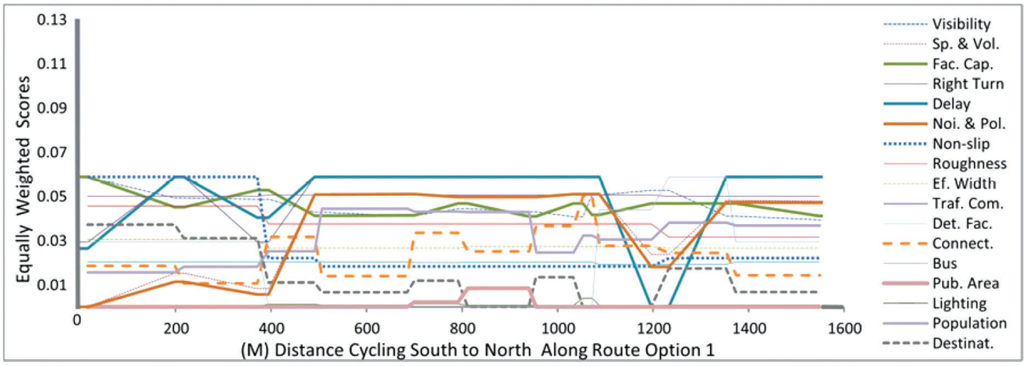


FIGURE 13.6 Route 1 sub-criteria segment and junction scores when equally weighted.

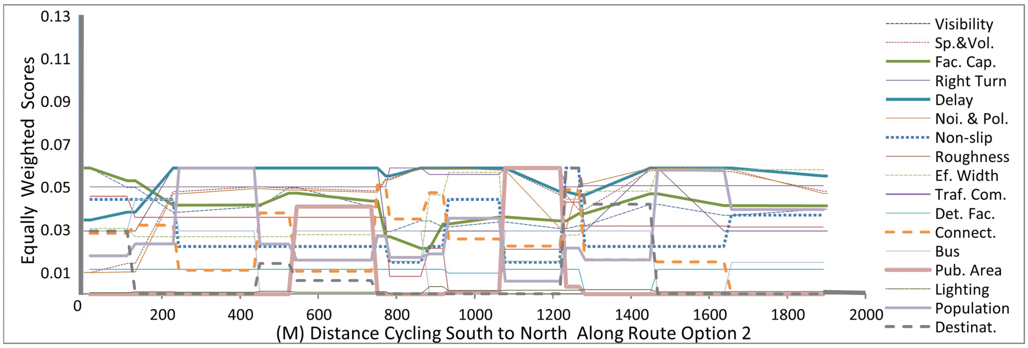


FIGURE 13.7 Route 2 sub-criteria segment and junction scores when equally weighted.

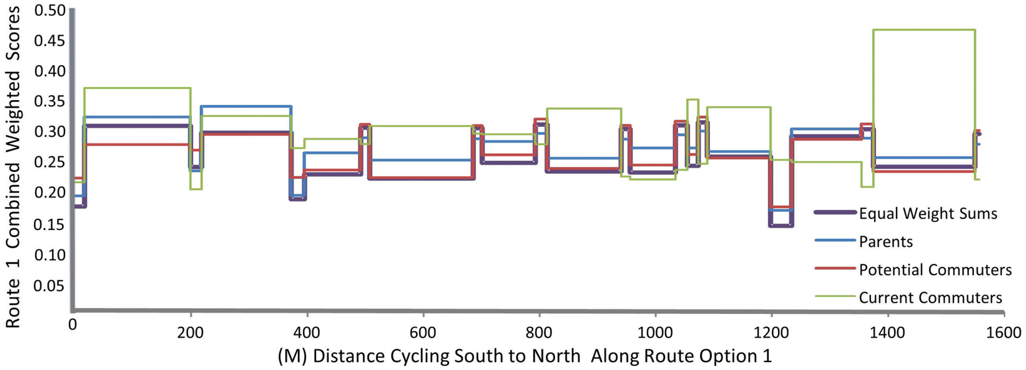


FIGURE 13.8 Route 1 summed sub-criteria segment and junction scores when weighted by target populations.

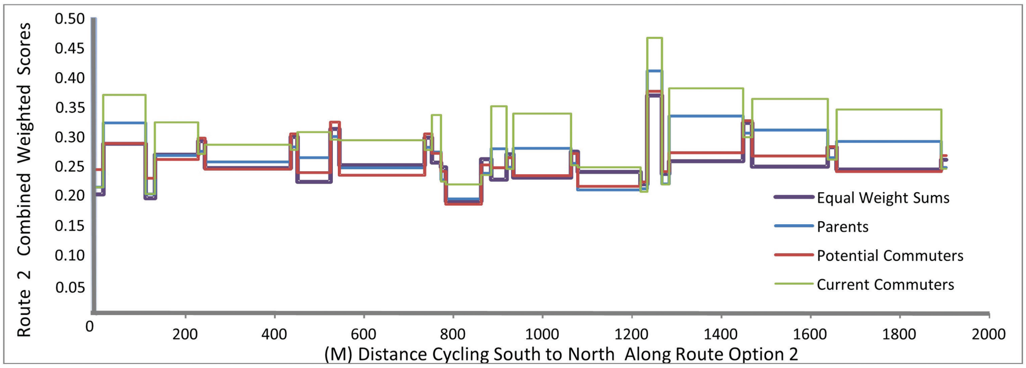


FIGURE 13.9 Route 2 summed sub-criteria segment and junction scores when weighted by target populations.

TABLE 13.2
Data Sets Used for the Study Area

Data Set	Pertinent Information	Information Obtained From (Local Organization)
July 2014 Bicycle Survey	Cycling perceptions & frequencies of > 1500 Christchurch residents	Karyn Teather (CCC Asset & Network Planning & UC Alumni)
Road Asset and Maintenance Management (RAMM)	Chip size, NAASRA roughness, ADT, traffic composition, reserve width & carriageway width	Binaya Sharma (CCC Asset & Network Planning, City Infrastructure Division) & updated via Counts website http://www.ccc.govt.nz/cityleisure/projectstoimprovechristchurch/transport/trafficcount/index.aspx
Cadastral parcels	Land use, frontage, dwelling units, commercial tenant	Josh Neville (UC Alumni) & updated via fieldwork
Road centre lines	Block length & road name	Aimee Martin (UC Alumni)
Roads miscellaneous	Speeds, facility photos, right-hand turn counts, directional delay	Manually recorded during fieldwork, samples of directional delay were timed during 8–9 am peak morning traffic for 20-minute intervals at each junction that would require a right turn
Bus	Bus stops, routes & shelters	Shannon Boorer (Environment Canterbury)

of segments and junctions. For instance, National Association of Australian State Road Authorities (NAASRA) roughness is different for each metre along the route, and in some places it is much worse than others. Despite these existing real-world variations, the performance measures require some level of aggregation to be practical. Segments and junctions are the building blocks of the network and thereby suited for scaling up to the city network. Thus, they were selected for this study.

Step 4 involves getting target populations to participate as stakeholders. Due to Christchurch's goal of increasing cycling's modal share, our research classified three target populations: current cycling commuters, potential cycling commuters and parents with children aged 10–17 years. Accordingly, three small sample groups were created. The participation in surveys and focus groups together totalled 66 individuals ($n=66$). The results produced included each person's preference ranking, which was then aggregated into a group criteria weighting scheme for their target population. These sample groups were not assumed to be entirely representative of the target populations of Christchurch. Rather, they served as an example of how personal preferences can be turned into weighting schemes for each target population. The 17 criteria were presented to them hierarchically with the seven main criteria as shown in Table 13.1.

It is then possible to visualise the individual sub-criteria scoring graphs and how they change with distance at different segments and junctions along each route. Figure 13.5 shows the summed version of these equal weight scores, displaying how many of the segments within the study area score only moderately in terms of bicycle-friendliness. This is because low scoring criteria such as lighting and adjacent non-residential destinations, as well as parks, displayed art and public areas (shown in the graphs as Pub. Area), were displayed as being equally important to effective width, detour factor and other sub-criteria. It was expected that these aforementioned criteria would score low, as this study area is a fairly typical Christchurch residential neighbourhood that borders large industrial and commercial districts.

These standardised segment and junction scores were then weighted to show the preferences of people who had participated as stakeholders. Remember, these are small samples, not significant representations of the true preferences of the target cyclist populations in Christchurch. The participants first ranked the main criteria and then the sub-criteria. Participants' results were then aggregated into the median for their target cyclist group. These tables show the rounded weights, but the procedure used fractions with non-rounded weights summing to the normalised '1'. This satisfies the major assumption of traditional MCA weighted summation.

13.3.1 RANKS CONVERTED TO MAIN CRITERIA WEIGHTS

Tables 13.3 through 13.5 present the main criteria weights (MCW) of the three cyclist groups targeted as derived from their rankings (Table 13.6).

TABLE 13.3
Main Criteria Weights of 18 Potential Cycling Commuters

Main Criteria Rank Set (Highest Ranking Criteria Listed First)	Median Stakeholder Rank	SDSS Weight (Rank/Rank Sum)
Junction safety	6	0.211
Directness & efficiency	4	0.140
Connectivity & transit Cohesion	4	0.140
Attractiveness	4	0.140
Trip generators & attractors	4	0.140
Capacity	3.5	0.123
Comfort	3	0.105
Sum	28.5	1.000

TABLE 13.4
Main Criteria Weights of 32 Current Cycling Commuters

Main Criteria Rank Set (Highest Ranking Criteria Listed First)	Median Stakeholder Rank	SDSS Weight (Rank/Rank Sum)
Junction safety	5.5	0.200
Directness & efficiency	4	0.145
Connectivity & transit cohesion	4	0.145
Capacity	4	0.145
Attractiveness	3.5	0.127
Trip generators & attractors	3.5	0.127
Comfort	3	0.109
Sum	27.5	1.000

TABLE 13.5
Main Criteria Weights of 16 Parents with Children Aged 10–17 Years

Main Criteria Rank Set (Highest Ranking Criteria Listed First)	Median Stakeholder Rank	SDSS Weight (Rank/Rank Sum)
Junction safety	7	0.226
Capacity	6	0.194
Trip generators & attractors	5	0.161
Directness & efficiency	4	0.129
Comfort	3	0.097
Attractiveness	3	0.097
Connectivity & transit cohesion	3	0.097
Sum	31	1.000

13.3.2 RANKS CONVERTED TO SUB-CRITERIA WEIGHTS

Having established relative weightings attached to different criteria, these criteria could then be scored for the two route options trialled for the Norwest Arc. Figure 13.5 shows the route segment and junction scores for the two options (start and end locations indicated by stars). Figures 13.6 through 13.9 show the segment scores for the criteria and targeted cyclist groups.

Both route options scored 6–7% higher for the current commuters than for potential commuters and parents of children 10–17 years. As we have noted previously, this is owing to the type of roads in this study area and how they score better with the combination of criteria preferred by the current commuters. These results support the theory that not all roads are equally suitable for groups with different levels of confidence and abilities (CROW, 2007). If these trends manifested themselves with representative sampled target populations, then it might require special interventions to accommodate these different groups.

As we expected, there was a reversal point (see Table 13.7) after the weights were significantly altered from equal criteria weighting. This indicates that the route chosen would have to be improved at its worst scoring junctions and segments prior to becoming significantly more suitable than the other route option.

This big shift in overall suitability was produced by the weights acting as linear transformations of the original performance values. In other words, the cyclist preferences and weighting schemes

TABLE 13.6
Sub-Criteria Weights of 32 Current Cycling Commuters

Main Criteria	Median Stakeholder Rank	SDSS Weight (Rank/Rank Sum)	Sub-Criteria Rank Sets	Median Stakeholder Rank	SDSS Weight (Rank/Rank Sum) × mc Rank
Junction safety	6	0.211	Visibility	2	0.084
			Volume & speed	1	0.042
			Facility capability	2	0.084
			sum	5	0.211
Directness & efficiency	4	0.140	Detour factor	1	0.028
			Right turns	2	0.056
			delay	2	0.056
			sum	5	0.140
Connectivity & transit cohesion	4	0.140	Connectivity	2	0.093
			Bus stops	1	0.047
			Sum	3	0.140
Attractiveness	4	0.140	Public place	2	0.047
			Noise & pollution	2	0.047
			Street lights	2	0.047
			Sum	6	0.140
Trip generators & attractors	4	0.140	Population	1.5	0.070
			Destinations	1.5	0.070
			Sum	3	0.140
Capacity	3.5	0.123	Effective width	2	0.082
			Traffic composition	1	0.041
			Sum	3	0.123
Comfort	3	0.105	Roughness	2	0.070
			Non-slip	1	0.035
			Sum	3	0.105
Sum	28.5	0.999	N/A	N/A	N/A

TABLE 13.7
Total Route Suitability Scores

Weighting Scheme	Total Route Suitability Scores	
	Route 1	Route 2
Equal weights	0.13841	0.13844
Current commuter*	0.65093	0.65097
Potential commuter	0.59580	0.58407
Parents of children aged 10–17	0.59417	0.58805

* Indicates a reversal point (when the ‘best’ scoring route changes).

change, but the original road scores remain the same. Changing weights leaves the potential for a reversal point (where the ‘best’ option changes) to be caused by a target population’s different preferences for one route over another (the routes having different road types, transecting different neighbourhoods, different densities of attractors and generators etc.). Weights change the total route suitability score and let it range from bad to good on the bicycle-friendliness scale of 0–1, with 1 being most friendly for that target population. Note also that the total suitability scores for

Routes 1 and 2 show very little difference when compared by the same target population. This is because both routes were similar in street design. Both route options score reasonably well for current cycling commuters, but less so for potential cycling commuters and parents of children aged 10–17 years. For these last two groups, both Routes 1 and 2 would require significant design improvements to be considered bicycle-friendly routes.

Target populations of any city likely have shifting preferences and experiences as time passes and cycling facilities improve. This is why regular feedback from these target populations should be gathered periodically to improve the design process. As shown in Table 13.8, additional information can be gained from these stakeholder sample groups: many times, the participants in our study mentioned past facilities as examples of either good or poor design in meeting their preferences and needs. This additional information highlighted where Christchurch's comprehensive cycling program could improve its efforts. Maps were presented to the participants, and by the end of the stakeholder engagement process, 66 people had marked intersections and segments that were on their way to work or school with ideas and suggestions for facility improvements.

TABLE 13.8
Comment Summary of Christchurch Cycling Focus Group

Comment Category	Comment Sub-Category	No. Times Mentioned in Focus Groups	%
Behaviour	Cyclist behaviour	7	4.5
	Driver behaviour	18	11.5
	Media/public perception/initiatives	11	7.1
	Pedestrian behaviour	2	1.3
Connectivity	Lack of options	4	2.6
Good facilities	Cycle lane separation	5	3.2
	Intersections	5	3.2
	Parked cars	4	2.6
Maintenance	Broken glass	2	1.3
	Roadworks	4	2.6
Navigation	General road segment Difficulty/danger	6	3.8
	Lane change difficulty	3	1.9
	Left-turn difficulty/danger	3	1.9
	Right-turn difficulty/danger	13	8.3
	Roundabout difficulty/danger	6	3.8
	Through intersection difficulty/danger	10	6.4
Obstruction/visibility	Parked cars	7	4.5
Poor facilities	Cycle paths designed around car parks/ bus stops	3	1.9
	Disjoint segment cycle lanes	2	1.3
	Major cycle paths too narrow	4	2.6
	No cycling facilities	8	5.1
	Shared cycle lane/footpath	6	3.8
	Transfer between segment cycle facilities & junctions with no facilities	4	2.6
	Unclear design	9	5.8
Traffic related	Bus conflict	4	2.6
	Congestion blocks junction cycle lane	2	1.3
	Road is too busy	2	1.3
	Truck conflict	2	1.3
Total		156	100.0

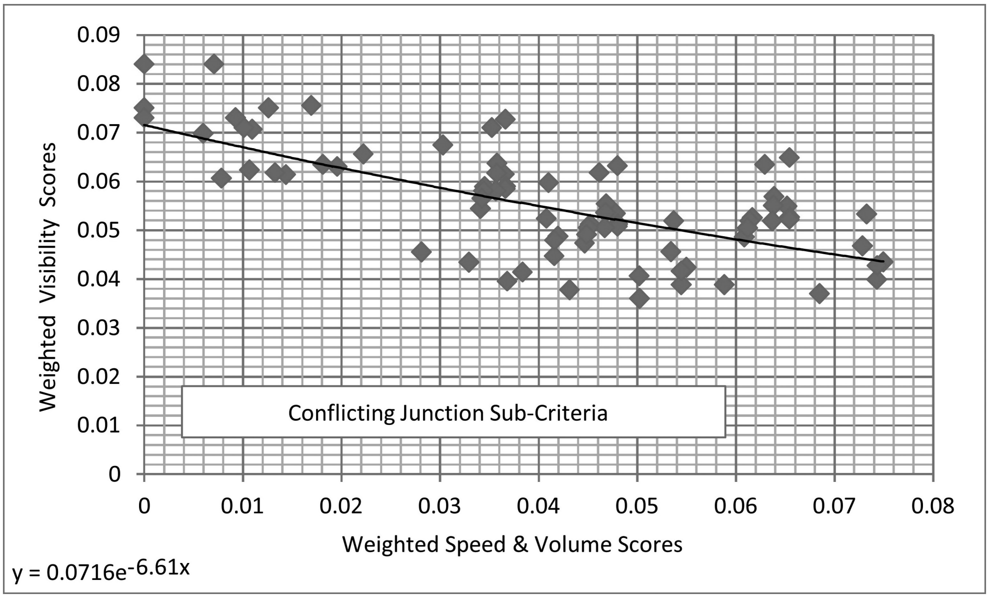


FIGURE 13.10 One of Christchurch supply-side criteria conflicts.

Knowing which designs and past projects the target populations perceive as successes or failures is important, as future projects will probably have to assign priorities among design ideals. This is especially important when target populations state their safety is being compromised by a past design (which may have got a high score in other, conflicting criteria).

Two desirable, bicycle-friendly criteria may work against each other, so that an increase of one leads to a decrease in the other. The results from our study also contain this general conflict, as illustrated in Figure 13.10. Even when different weighting schemes are applied, as shown in the figure, there remains a non-linear, moderately strong negative correlation between the study area's increasing speed and volume in relation to junction visibility scores. Visibility, volume and speed are some of the most important variables for reducing collision severity and fatality rates (Ehrgott et al., 2012; Environment Canterbury, 2005), and these are commonly considered in facility engineering designs in New Zealand (Land Transport Safety Authority, 2004). Designing for a single cycle route will bring with it both types of criteria. Mitigating the effects of the inherent compromises this demands is the difficult job facing facility designers and engineers. A standardised bicycle route assessment would provide a way of structuring the complications and prioritizations involved with these compromises.

13.4 IMPROVEMENTS FOR THE FUTURE

For stakeholder participation to become representative of Christchurch's target cycling populations, involvement would need to be implemented on a larger scale than that of our study. This could be undertaken through surveys or public-opinion websites with a larger sample of participants for each target population. Without anticipating sample bias, results from any assessment (even assessments with fewer criteria or other MCA techniques) may give misleading conclusions.

Though scalability was not within the scope of this study, the equations we have presented were modified from their original sources so as to be scalable in theory. If future research demonstrates that these types of MCA equations for cycle route design are indeed scalable to whole networks, then it would dramatically change how the industry assesses infrastructural interventions for target populations. Network assessment could identify vulnerabilities for a city's target cycling populations due to network fragmentation and/or other design failures. This would be useful for countries like the U.S.A, where many city-wide cycleway programmes have left networks fragmented by well-designed, yet disconnected individual projects (Schoner and Levinson, 2014). Future studies could look at how the needs of multiple target populations could be streamlined across a cycle network and whether multiple cycle networks are needed within any given city.

13.5 CONCLUSION

A real cycle route is not simply an aggregated score but rather the sum of its many diverse parts, and its bicycle-friendliness can change over space and time. Consequently, cycle route designers are better equipped if they have access to quantitative spatial assessments that: (1) give detail at junction and segment levels; (2) can assess the preferences of any given target group for any of the criteria involved and the overall design of the planned cycle route; and (3) can improve future designs by triggering reactions to past designs. Systematically integrating target populations into the process of cycle route design can strengthen the justification for city-wide cycle programmes and encourage public support for any individual construction project.

Future studies could explore the dynamics of implementing standardised bicycle-route assessment procedures in different situations and different city environments. It would especially help policy-makers to better understand how stakeholder participation can be applied to cycle route design on a city-wide scale. Standards need to be better defined in order for quantitative bicycle-route assessments to operate efficiently within city managements. Although assessment results support the monitoring and processing of detailed data, ultimately reaching strategic transport targets requires laws and policies for a strong and comprehensive foundation. Without some kind of regional or nation-wide assessment, bicycle routes will still be designed using criteria of a priori importance, but the quality of the work will continue to be dependent on locally available experts and is likely to vary from project to project.

REFERENCES

Butler, A. (2015). *Multiple Criteria Bicycle Route Assessment Integrating Demand, Supply & Stakeholder Perceptions for a Spatial Decision Support System in Christchurch, New Zealand*. Retrieved from https://webapps.itc.utwente.nl/librarywww/papers_2015/msc/upm/butler.pdf

Canterbury Regional Transport Committee. (2012). *Canterbury Regional Land Transport Strategy 2012–2042*. Christchurch, New Zealand. Retrieved from http://ecan.govt.nz/our-responsibilities/regional-land-transport/pages/regional-land-transport-review.aspx

Christchurch City Council. (2016). *Major Cycle Route Network Updates: Christchurch City Council*. Retrieved April 8, 2016, from http://www.ccc.govt.nz/transport/cycling/cycleways/latest-cycleways-news/

CROW. (2007). *CROW Design Manual for Bicycle Traffic*. CROW. Retrieved from http://www.crow.nl/shop/productDetail.aspx?id=889&category=90

Damant-Sirois, G., Grimsrud, M., & El-Geneidy, A. M. (2014). What's your type: A multidimensional cyclist typology. *Transportation*, *41*(6), 1153–1169. https://doi.org/10.1007/s11116-014-9523-8

Ehrgott, M., Wang, J., Raith, A., & Van Houtte, C. (2012). A bi-objective cyclist route choice model. *Transportation Research Part A: Policy and Practice*, *46*(4), 652–663. https://doi.org/10.1016/j.tra.2011.11.015

Environment Canterbury. (2005). *Cycling in Canterbury: Strategy for the Development of a Regional Network of Cycle Routes*. Christchurch, New Zealand. Retrieved from http://ecan.govt.nz/publications/Plans/CinC.pdf

Geneletti, D. (2010). Combining stakeholder analysis and spatial multicriteria evaluation to select and rank inert landfill sites. *Waste Management (New York, N.Y.)*, *30*(2), 328–337. https://doi.org/10.1016/j.wasman.2009.09.039

Hajkowicz, S., & Higgins, A. (2008). A comparison of multiple criteria analysis techniques for water resource management. *European Journal of Operational Research*, *184*(1), 255–265. https://doi.org/10.1016/j.ejor.2006.10.045

Keshkamat, S., Looijen, J., & Zuidgeest, M. (2009). The formulation and evaluation of transport route planning alternatives: a spatial decision support system for the Via Baltica project, Poland. *Journal of Transport Geography*, *17*(1), 54–64. https://doi.org/10.1016/j.jtrangeo.2008.04.010

Kroesen, M., & Handy, S. (2013). The relation between bicycle commuting and non-work cycling: results from a mobility panel. *Transportation*, *41*(3), 507–527. https://doi.org/10.1007/s11116-013-9491-4

Land Transport Safety Authority. (2004). *Cycle Network and Route Planning Guide*. Retrieved from http://www.nzta.govt.nz/resources/cycle-network-and-route-planning/

Landis, B. W. Vattikuti, V.R., Brannick, M.T. (1997). Real-Time Human Perceptions: Toward a Bicycle Level of Service. Transportation Research Record, (1578), pp. 119–131.

Landis, B., Vattikuti, V., Ottenberg, R., Petritsche, T., Guttenplan, M., & Crider, L. (2003). Intersection level of service for the bicycle through movement. *Transportation Research Record: Journal of the Transportation Research Board*, *1828*, 101–106. Retrieved from http://trb.metapress.com/content/r6t63r2g723661u8/

Malczewski, J. (2006). GIS-based multicriteria decision analysis: A survey of the literature. *International Journal of Geographical Information Science*, *20*(7), 703–726. https://doi.org/10.1080/13658810600661508

Mendoza, G., & Martins, H. (2006). Multi-criteria decision analysis in natural resource management: A critical review of methods and new modelling paradigms. *Forest Ecology and Management*, *230*(1–3), 1–22. https://doi.org/10.1016/j.foreco.2006.03.023

NZ Transport Agency. (2016). *Urban Cycleways Programme*. Retrieved May 11, 2016, from http://www.nzta.govt.nz/walking-cycling-and-public-transport/cycling/for-people-involved-in-cycling-programmes-and-projects/urban-cycleways-programme/

Pomerol, J.-C., & Barba-Romero, S. (2000). *Multicriterion Decision in Management: Principles and Practice*. Springer Science & Business Media. Retrieved from http://books.google.com/books?hl=en&lr=&id=mNOKayvMqH4C&pgis=1

Schoner, J. E., & Levinson, D. M. (2014). The missing link: Bicycle infrastructure networks and ridership in 74 US cities. *Transportation*, *41*(6), 1187–1204. https://doi.org/10.1007/s11116-014-9538-1

Sharifi, M. (2004). Site selection for waste disposal through spatial multiple criteria decision analysis. *Journal of Telecommunications and Information Technology*, *3*, 28–38. Retrieved from http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-BAT3-0012-0021

Sharifi, M., Boerboom, L., Shamsudin, K., & Veeramuthu, L. (2006). Spatial multiple criteria decision analysis in integrated planning for public transport and land use development study in Klang Valley, Malaysia. *ISPRS Technical Commission II Symposium*, 85–91. Retrieved from http://www.isprs.org/proceedings/XXXVI/part2/pdf/sharifi.pdf

Thomopoulos, N., & Grant-Muller, S. (2012). Incorporating equity as part of the wider impacts in transport infrastructure assessment: an application of the SUMINI approach. *Transportation*, *40*(2), 315–345. https://doi.org/10.1007/s11116-012-9418-5

Urbanczyk, R. (2010). *PRESTO Cycling Policy Guide Promotion of Cycling*. Retrieved from http://www.rupprecht-consult.eu/uploads/tx_rupprecht/PRESTO_Cycling_Policy_Guide_Promotion.pdf

Yang, C. H., & Regan, A. C. (2012). A multi-criteria decision support methodology for implementing truck operation strategies. *Transportation*, *40*(3), 713–728. https://doi.org/10.1007/s11116-012-9432-7