Selecting a Portfolio of Cycling Projects

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Abstract

At present, Auckland's cycling infrastructure is being developed not only to address problems associated with global warming, but also to promote healthier forms of transportation. Currently, the New Zealand Transport Agency (NZTA) employs a six stage decision making process when deciding which proposed cycling projects should be implemented. Here, the primary focus is to calculate the benefit to cost ratio for all proposed feasible projects and then to select those which perform well in this decision criterion within the constraint of a given cycling budget. Two weaknesses in this approach are the use of an unreliable demand forecasting model and the failure to capture interdependencies between proposed projects. Thus, a new methodology was developed to overcome these weaknesses and a focus area within the Auckland region was selected to demonstrate this improved process. A vital component in this methodology was to perform a cycling assignment on projects both individually and in conjunction with each other to determine the number of existing and new cyclists that are expected to use the new facilities. These forecasts were then used to calculate the benefit to cost ratios and finally, a linearised quadratic knapsack formulation was used to select the optimal portfolio of cycling projects.

Key Words: Benefit to cost ratio, Cycling assignment, Quadratic knapsack problem.

1 Introduction

The issue of global warming has assumed significant proportions in the world today. Great concern surrounds the large quantities of greenhouse gases such as carbon dioxide which are trapping infrared radiation in our atmosphere. Recent studies have shown that the carbon dioxide that is produced globally from the burning of fossil fuels such as petrol, diesel and ethanol is increasing by three percent every year (World Resources Institute, 2010). Considering that one of the main users of such fossil fuels are automobiles, sustainable alternative modes of transportation that do not rely on fossil fuels must be considered in order to prevent this statistic from increasing.

The New Zealand Transport Agency (NZTA) has recognised that active modes of transport such as walking and cycling should be promoted. Not only do these modes have atmospheric benefits, but they are also believed to alleviate congestion, help improve travel times for all road users and improve the reliability and resilience of the transport networks (NZ Transport Agency, 2009). Additionally, there are also clear health benefits which are associated with these active modes of transport.

In 2008, the NZTA set a target to double walking and cycling modes of transport to 30% of total trips by 2040 by building and maintaining quality facilities within the

Auckland urban and peri-urban areas (Hinton & Teh, 2008). This was to be achieved primarily by the addition of cycling facilities to state highways throughout Auckland as these highways are viewed to be vital in connecting and binding communities and facilitating economic development. As a result of this, potential cycling projects were analysed in the Southern, Western and Northern regions of Auckland. However, implementing the entire list of these projects is not possible given a cycling budget provided by the government.

Thus, the aim of this research project is to select a portfolio of potential cycling projects within the Auckland region that are beneficial to the cycling infrastructure, using an improved portfolio selection strategy that overcomes flaws in the current portfolio selection strategy.

2 Potential Cycling Projects

According to the Auckland Region Walking and Cycling Strategy (Hinton & Teh, 2008), in 2008 NZTA officials along with representatives from the Auckland Regional Transportation Authority (ARTA) developed a list of 79 proposed walking and cycling projects within the Auckland region. These projects were compiled from the individual project lists that were considered in the Auckland, North Shore, Waitakere, Manakau, Rodney, Papakura and Franklin regions.

3 Economic Evaluation Manual

The Economic Evaluation Manuals (Volumes 1 and 2) (EEM1 and EEM2), are documents created in 2009 by the NZTA which cover the economic efficiency evaluation of demand management and transport services activities for land transport (*EEM2*, 2009). For this research project the main section that was taken into consideration was Chapter 8 from EEM2 which includes the evaluation of walking and cycling facilities. Additionally, the procedure that was used to evaluate the new proposed projects by calculating a facilities benefit to cost ratio (BCR) was the Simplified Procedure 11 (SP11), which is specific to the evaluation of walking and cycling facilities. The BCR underpins the basis of the current portfolio selection strategy that the NZTA presently uses, and thus must be explored further.

4 Benefit to Cost Ratio Components

As mentioned in Section 3, the main component of the SP11 procedure is the BCR calculation of a new facility. The BCR value is used when determining the feasibility of a project and whether it should proceed to later stages in the evaluation process. The BCR for a new facility overall is defined as the following:

$$BCR(facility) = \frac{Benefit\ (facility)}{Cost\ (facility)}.$$

Formula 4.1: Benefit to Cost Ratio for a Facility.

In order for the BCR to be calculated as a ratio it is essential that we are able to express the benefits of a new facility in terms of monetary values. For this purpose, the Consumer Surplus Methodology is employed when determining the benefits with monetary value (*EEM2*, 2009). In this methodology, each of the types of benefits that a new facility will produce is monetised according to a consumers' willingness to pay for this benefit. The components of the benefits of a new facility that are thus considered for BCR calculations (as they can be monetised) are the travel time, vehicle operating, crash cost, pedestrian and cyclist, seal extension and passing lane, carbon dioxide and other tangible benefits.

In regards to the costs of a new facility, two main costs that are considered in the BCR calculations are the capital and maintenance costs. The capital costs are those which are required to bring the cycling facility to a commercially appropriate standard while maintenance costs are those which are incurred in the day to day running of the new facility. The costs are estimations and primarily based on the size of a new facility.

5 Demand Forecast

A common component in determining the travel time, the vehicle operating, pedestrian and cyclist and carbon dioxide savings is the demand forecast for a new facility. Since this is an important component of the benefit calculations, it is essential that we fully understand how these forecasts by the NZTA are currently estimated. The demand forecast is the number of cyclists that are forecasted to use the new cycling facility and consist of two components: existing cyclists and new cyclists.

Existing cyclists are frequent Auckland cyclists who are expected to use a facility if it is constructed. According to the SP11, the existing cyclists are estimated using observational data where the current numbers of cyclists are manually counted between the times of 7:00am-9:00am and 4:00pm to 6:00pm.

New cyclists are those who are assumed will start to cycle due to the construction of the new facility. These new cyclists are made up of new commuter cyclists (those who cycle as a mode of transportation to work) and new other cyclists (those who will cycle for other purposes, e.g. recreation). The numbers of new cyclists for a facility are estimated using the "Buffer Zone" method. The basis of this method is that buffer zones with a certain radius around a facility are analysed and from this a forecast is made for the number of new commuter and other cyclists based on population densities.

6 Current Portfolio Selection Strategy

So far, the fundamentals of the BCR calculations have been explored, where the various components of the benefits and costs have been defined. Following this, we can now examine the NZTA's current portfolio selection strategy in order to identify any weaknesses so that improvements that can be made. An overview of the current six stage selection process is as follows.

Stage 1 (Identification): This stage involves listing all possible walking and cycling projects that adjoin or cross the state highway network. This list is compiled with the Auckland City Council's support and has connectivity with the local network.

Stage 2 (Consultation): In this stage, there is a consultation with Auckland's seven local authorities and ARTA in order to discuss specific projects that should be taken into consideration for each of the seven different areas. This is when the list of projects for the various regions are collated.

Stage 3 (Assessment): In this stage, all of the projects within the different areas are ranked according to defined assessment criteria. There are a total of six assessment criteria for which each of the projects is awarded a score between 1 and 3. These scores are then summed to give a total assessment score for a project.

Stage 4 (Ranking and Urgency): In this stage, the remaining projects are are tagged as urgent (U), under investigation (I) or pending (P) depending on their urgency.

Stage 5 (Prioritisation): In this stage, a shortlist of projects is determined based on the assessment criteria and urgency scores. Here projects which score above 9 that are also deemed 'U' are priority projects for investigation while projects which score above 12 that are also deemed 'I' are projects for investigation.

Stage 6 (Feasibility and Selection): In this stage, for each of the shortlisted projects, the benefits, costs and hence the BCR is determined using the SP11 procedure. This list of projects is then ranked according to the largest to smallest BCR values. A final portfolio of projects is selected for implementation by choosing the projects with the largest BCRs within the constraints of the cycling budget.

7 Weaknesses in Current Portfolio Selection Strategy

The analysis of the NZTA's current portfolio selection strategy has highlighted some weaknesses that must be addressed in order to obtain a more thorough portfolio selection strategy. The main weaknesses have been identified in Stages 5 and 6 of the current strategy and are as follows.

The first major weakness identified was that the current methodology does not fully capture interdependencies between different projects. While the benefits, costs and the BCR are calculated for all individual projects in Stage 6, there is no real investigation into the benefit of placing two or more projects in conjunction with each other. While there is an attempt to consider these interdependencies in Stage 5 (i.e. 'Urgent' projects potentially are those which could provide missing regional cycle network links), there is currently no established mathematical method of modelling this.

The second main weakness that was found in the current methodology was the approach used to forecast the demand. Both the observational data used to forecast the number of existing cyclists and the 'Buffer Zone' method used to forecast the number of new cyclists are not particularly accurate and do not truely represent the number of cyclists expected to use a facility. As mentioned in Section 5, the number of cyclists that are estimated to use a new facility is a large contributor to the benefits for a facility and thus must be estimated as accurately as possible.

8 New Portfolio Selection Strategy

Given that the main weaknesses of the current methodology have been established, a new portfolio selection strategy which addresses these issues must be developed. Since the identification and consultation stages of the current strategy involve primarily determining the list of proposed projects, there is not much change that can be suggested there. Similarly, the assessment, ranking/urgency and prioritisation stages involve primarily short listing the large list into an 'urgent' list, and thus not much alteration can be imposed there either. Therefore, the main stage which will be explored is the feasibility and selection stage, where from the list of 'urgent' projects, a final portfolio can be selected. Thus a new portfolio selection strategy has been developed (see Figure 8.1). A description of these stages is as follows below.

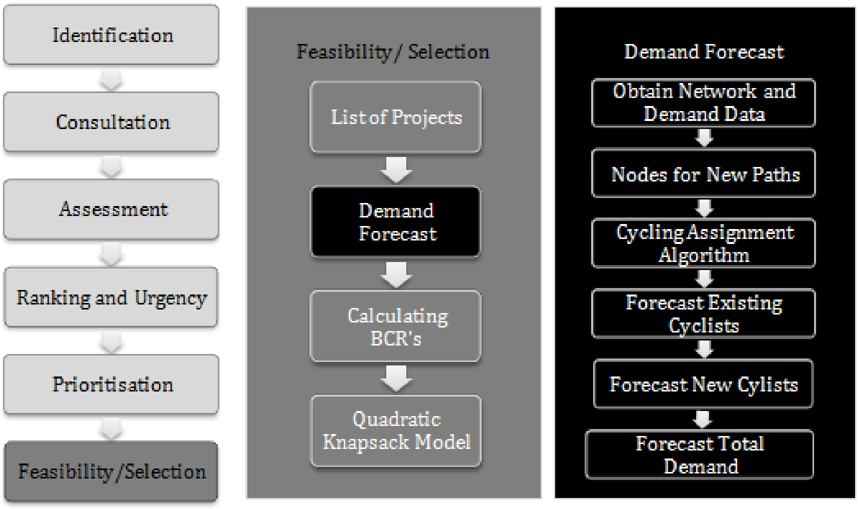

Figure 8.1: New Portfolio Selection Strategy with Demand Forecast Methodology.

8.1 Stage 1: Obtaining a List of Projects

The first stage of the new portfolio selection strategy involves obtaining a list of projects from which the optimal portfolio of cycling projects will be chosen. As mentioned previously, Stages 1-5 of NZTA's current portfolio strategy involves primarily obtaining this short list from the entire list of projects, and thus in reality, this stage will already be near completion at the end of Stage 5 of the original methodology.

8.2 Stage 2: Demand Forecast

The second step in the new methodology is to obtain the demand forecasts individual projects and for different combinations of projects. The reason for considering combinations of adjacent projects is because this is where the interdependency flaw is overcome. By forecasting demand and calculating the BCRs for projects alone and in conjunction with each other we can identify the benefit or disadvantage of projects implemented together.

Obtain Network and Demand Data: The first step in forcasting the demand is to aquire the data sets that are required in the cycling assignment. The first data input required is a network representation of the area that the projects are within. This network extracted contains all roads on which bikes are allowed. The second major data input which is required for the cycling assignment algorithm is the cycling demand matrix. This demand data is presented in a matrix and represents the information on how many cyclists currently travel from various origins to various destinations in the Auckland network. The demand matrix is required as these are the cyclists that will be used to determine the number of existing cyclists on each of the new proposed paths.

Nodes for New Paths: The second step is to create the new proposed projects using nodes from the current network which can be inserted into the Auckland network when required. The reason for this is that the new cycle paths obviously do not exist in this network and hence they must be added in.

Cycling Assignment Algorithm to Forecast New Cyclists: The third step was to develop an algorithm that performs the cycling assignment to estimate the number of existing cyclists. The code that was implemented for this algorithm was written in C and was compiled and run using the operating system Linux. The initial algorithm for the cycling assignment is as follows (based on orginal code written by Dr. Andrea Raith).

Cycling Assignment Algorithm:

1. *Read in the demand matrix from a data file which contains information about the total number of origin-destination (OD) nodes and the demands between all OD pairs.*
2. *Read in the Auckland network from a data file.*
3. *Convert the Auckland network to the forward star representation.*
4. *Start the clock.*
5. *Insert the new arcs which represent the new projects from a data file into the forward star representation.*
6. *Set a modal share (percentage of cyclists) and a cycling tolerance (number of cyclists for which a demand less than this is ignored).*
7. *For each OD pair in the demand matrix, do the following:*
    - 7.1. *If the source node and destination node are not the same, do the following:*
        - 7.1.1. *Set the source node, destination node and the demand for this pair.*
        - 7.1.2. *Determine the cycling demand using the cycling multiplier.*
        - 7.1.3. *If the cycling demand is greater than the cycling tolerance, do the following:*
            - 7.1.3.1. *Use the Bi-objective Label Setting Algorithm to find the set of efficient paths (those which are better in at least one component in comparison to the inefficient solutions, and are not equal) from the source node to the destination node.*
            - 7.1.3.2. *Determine the flow on each efficient path by distributing demand evenly amongst all efficient paths.*
            - 7.1.3.3. *Backtrack along all arcs which make up each efficient path and allocate the flow as determined above.*
8. *Print out the total flow on the new arcs.*
9. *End the clock.*

Forecast New Cyclists and Total Demand: Performing this cycling assignment algorithm on the required network will yield the number of existing cyclists expected to use the new facility. In order to obtain the number of new cyclists expected to use the facility, the existing demand figures and appropriate multipliers are used. The sum of the existing demand and the new demand yields the total demand for a facility.

8.3 Stage 3: Calculating Benefits and Costs

The third stage in the overall portfolio selection strategy is to obtain the benefits and costs for each of the paths individually and combined, which will in turn be used in the optimisation model. Both the benefits and the costs are calculated using an updated EXCEL workbook, which is based on an original workbook which was developed by the NZTA and contains the procedures for calculating the benefits and costs for a proposed new facility as shown in SP11.

8.4 Stage 4: Quadratic Knapsack Model

The final stage in the new portfolio selection strategy is to select the optimal portfolio of cycling projects using the Quadratic Knapsack Problem linearised (QKPL) as shown below. Here, the objective is to maximise the sum of the individual benefits as well as the additional benefits from two projects in conjunction with each other. The only constraint is that the sum of the costs of the implemented projects are within a defined budget.

Decision Variables:
x_i = *Implementing proposed project i.*
x_j = *Implementing proposed project j.*
y_{ij} =*Implementing proposed projects i and j in conjunction.*
Parameters:
b_j = *Benefit of implementing proposed project j.*
bij = Additional benefit of implementing proposed projects i and j in conjunction.
w_j = *Total cost of implementing proposed project j.*
c = Total cycling budget.

$$(QKPL): maximise \sum_{j=1}^{n} b_j x_j + \sum_{i=1}^{n}\sum_{j=1}^{n} b_{ij} y_{ij}$$

$$subject\ to \sum_{j=1}^{n} w_j x_j \le c,$$

$$y_{ij} \le x_i$$

$$y_{ij} \le x_j$$

$$x_{j\,,}\, x_j\,, y_{ij} \in \{0,1\},\ \ i,j = 1 \ldots n.$$

Formula 8.1: Linearised Quadratic Knapsack Formulation.

9 Selected Focus Area

Given that the new portfolio selection strategy has now been described, the next step is to demonstrate that this methodology performs well in practice. In order to show this, a focus area within the Auckland region was selected. This section performs the four step methodology as described in Section 8 on the focus area in order to obtain the optimal cycling portfolio.

9.1 Stage 1: Obtaining a List of Projects

The focus area that was selected to demonstrate the new selection strategy is in the Auckland City region, and is the corridor along the Southern motorway which runs from Princes Street in Otahuhu to Carlton Gore Road in Newmarket.

The next step was to split this focus area, keeping in mind already proposed projects. Thus, the area was divided according to three projects namely Auckland City Proposed Cycling Project 8 (A08), Auckland City Proposed Cycling Project 7 (A07) and a New Project (NP). The NP was added in order to add connectivity to the Central Business District (CBD), as this is a major destination for many commuter cyclists. Since not much analysis can be done by simply considering three projects, A08, A07 and NP have been split into a total of seven paths that will be analysed when looking at interdependencies

9.2 Stage 2: Demand Forecast

Given that the focus area and the different paths have been selected to demonstrate the new methodology, the next step is to forecast the number of existing cyclists and the number of new cyclists which are expected to use the paths individually and in conjunction with adjacent paths. As mentioned previously, the number of existing cyclists are forecast using the cycling assignment algorithm. The Auckland network data set that was used was extracted from OpenStreetMap which is an online representation of geographical data and maps. The demand matrix data set used contains origins and destinationsa and values from the Auckland Transport Authority Model 3 (ART3) model, which was developed by ARTA. For the number of new cyclists, the number of new commuter cyclists are taken to be 19% of the existing cyclists while the number of new other cyclists are taken to be 15% of existing cyclists.

The final demand forecast figures which consist of the sum of the existing and new cyclists are as shown in Table 9.1. Here we see that the first run consists of inserting all seven paths into the network, runs 2 to 8 consist of inserting each of the paths individually and runs 9 to 14 consist of inserting combinations of two adjacent paths.

	Run													
New Arc	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	**66**	**59**	0	0	0	0	0	0	**65**	0	0	0	0	0
2	**163**	0	**124**	0	0	0	0	0	**128**	**136**	0	0	0	0
3	**334**	0	0	**138**	0	0	0	0	0	**157**	**273**	0	0	0
4	**294**	0	0	0	**157**	0	0	0	0	0	**218**	**209**	0	0
5	**435**	0	0	0	0	**185**	0	0	0	0	0	**312**	**209**	0
6	**702**	0	0	0	0	0	**355**	0	0	0	0	0	**448**	**535**
7	**881**	0	0	0	0	0	0	**767**	0	0	0	0	0	**833**

Table 9.1: Final Demand Forecasts for Individual ad Combinations of Paths.

From these results two observations can be made. Firstly, the largest flows are produced when the entire corridor is considered, the second largest flows are produced when two paths are considered in conjunction with each other and the smallest flows are produced when paths are considered alone. This clearly shows that examining combinations of paths (and thus projects) is a vital component that must be considered when forecasting demands. Secondly, as the paths get closer to the city, the demands also progressively increase. This is also to be expected as the CBD is a major destination for most cyclists.

9.3 Stage 3: Calculating Benefits and Costs

Now that all the demand forecast figures have been obtained for the focus area, the next step is to obtain the benefits (these include the individual benefits and the additional combined benefits) as well as the costs of the individual paths using the updated SP11 EXCEL workbook. The values for the benefits of individual projects, the additional benefits of projects in conjuction with each other are as follows:

Comb. Number	**Arcs**							**Existing Demand**	**New Demand**	**Benefits**				**Total Benefit**
	1	**2**	**3**	**4**	**5**	**6**	**7**			**TTS**	**VOS**	**PCS**	**CDS**	
2								44	15	33099	1701	38444	68	73312
3								92	31	57398	2951	81141	118	141608
4								103	35	31622	1626	90690	65	124003
5								117	40	75627	3889	102851	156	182523
6								138	47	63595	3269	121259	131	188254
7								265	90	82224	4227	233179	169	319799
8								572	195	340173	17489	503300	700	861662

Table 9.2: Final Benefits for Individual Paths in Focus Area.

Comb. Number	**Arcs**							**Add. Existing Demand**	**Add. New Demand**	**Additional Benefits**				**Additional Total Benefit**
	1	**2**	**3**	**4**	**5**	**6**	**7**			**TTS**	**VOS**	**PCS**	**CDS**	
9								8	3	11260	580	7180	23	19043
10								23	8	21638	1114	20489	45	43286
11								146	50	139575	7175	128760	287	275797
12								135	46	149137	7667	118385	307	275496
13								88	30	67788	3486	77289	139	148702
14								183	62	165397	8504	160812	340	335053

Table 9.3: Final Benefits for Combinations of Paths in Focus Area.

In regards to the calculations for the cost of implementing the individual projects, firstly it has been assumed that the capital costs considered are identical for all paths. Secondly, it has been assumed that the maintenance costs considered are linearly related to the total length of the path. The costs of the individual projects are as follows:

Path	**Length**	**Capital Cost**	**Maintenance Cost**	**Total Cost**
1	2405	1000000	3608	1003608
2	1976	1000000	2964	1002964
3	974	1000000	1461	1001461
4	2054	1000000	3081	1003081
5	1465	1000000	2198	1002198
6	985	1000000	1478	1001478
7	1888	1000000	2832	1002832

Table 9.4: Total Costs for each Path in Focus Area.

9.4 Stage 4: Quadratic Knapsack Model

Based on the results obtained from the quadratic knapsack model linearised which was implemented in AMPL using the benefits and costs obtained above, the recommended optimal portfolio of cycling paths for the focus area consists of path 4,5,6 and 7 (as highlighted in Figure 9.1) and has an optimal objective of $2311489.40. This portfolio clearly supports the theory of considering interdependencies between projects as all the paths selected form a continuous corridor. Additionally, these paths are closest to the CBD and had the largest flows, which support the theory that the demand forecast is a vital component in the selection of the cycling portfolio.

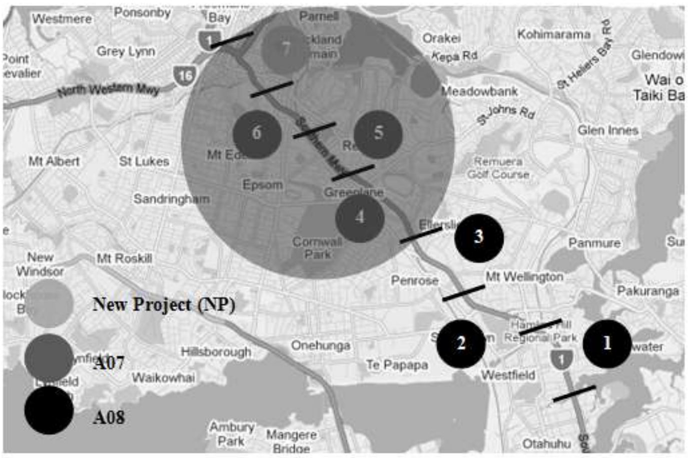

Figure 9.1: Optimal Portfolio of Cycling Projects for Focus Area (Google Maps, 2010).

10 Future Work

This research project has involved primarily altering the NZTA's current portfolio strategy in order to develop a new strategy which has a more accurate demand forecast and takes into consideration interdependencies between projects. While this has been proved to be an effective strategy, there are five major opportunities for future work:

1. Testing projects which have a reduced additional joint benefit.
2. Exploring the concept of induced demand. Induced demand is where due to the introduction of new facility, there will be additional demand for that facility.
3. Consider larger combinations of adjacent projects.
4. Applying this new methodology to a larger project set.
5. Explore methods used to split the demand amongst the efficient paths in the cycling assignment algorithm other than evenly.

11 Conclusions

In this research project we have:

- Fully understood the NZTA's current portfolio selection strategy, its various components and the list of potential cycling projects.
- Critically identified flaws in the current portfolio selection strategy and thus derived a more thorough portfolio selection strategy.
- Focused attention on a particular area within Auckland from the given list of potential cycling projects, applied the improved portfolio selection strategy and obtained an optimal portfolio of cycling projects in order to verify that the new strategy is appropriate.

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