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Intervening in the trip to work

A system dynamics approach to commuting and public health

Alexandra Kathryn Macmillan

Abstract

Background
Car use is the dominant mode of transport in short, habitual journeys to work in many cities, including Auckland. It allows access to a range of employment and training while enabling families to manage other responsibilities. However, car dependent commuting has significant negative effects for commuters, the wider community, and local and global ecosystems. Existing evidence about harms is sufficient to seek a commuting mode shift for environmental, health and equity benefits. Although some of these benefits are already considered in transport planning to a varying extent, there are considerable challenges of complexity and implicit trade-offs, among competing interests and between outcomes. Cross-disciplinary discourses have identified principles for effective policy decisions in complex systems such as this, including a systems approach, transdisciplinarity, community participation and a social justice focus. These principles formed the basis for the thesis.

Aims
1. To develop a comprehensive conceptual model of the trip to work and public health that synthesises knowledge from epidemiology, communities and policy makers
2. To develop a commuting and public health simulation model that could quantify a range of outcomes for some particular policy options
3. To use this model to identify effective policy levers for intervening in commuting patterns to improve public health outcomes
4. To test the utility of the modelling methodology for integrating public health outcomes in a more participatory approach to transport policy making

Methods
A review of the complex links between commuting and health was undertaken using two ecosystem health frameworks. I then investigated how these links have been incorporated into New Zealand’s transport policies. Participatory system dynamics (SD) modelling was used to combine policy, community and academic knowledge. SD modelling enables the simulation of complex systems characterised by feedback, delay, non-linear relationships and tipping points. Interviews and workshops with community, health and policy stakeholders led to the development of causal loop diagrams (CLDs) connecting influences on mode share with broad wellbeing outcomes. One element of the CLDs was developed into a simulation model incorporating best evidence for Auckland. Policy scenarios were simulated to consider their relative effectiveness for meeting identified policy targets and public health outcomes. The model was shared with regional and national decision makers to influence policy.

Results
The review and policy analysis identified a complex range of connections between commuting and public health and found these have been poorly incorporated into transport planning in New Zealand to date. Nine
commuting and public health themes emerged from the qualitative modelling process: pedestrian and cyclist safety; relative attractiveness of public transport; neighbourhood security; time pressure and employment accessibility; workplace support for different modes; participation and leadership in planning; environmental and cultural wellbeing; and “car culture”. These were developed into CLDs. Causal loops relating to cycling were developed into a simulation model, incorporating the following scenarios to 2051: business-as-usual; the planned regional cycle network; physically separated cycle lanes on all arterial roads; and region-wide “self-explaining” local roads. Combining the last two policies was most likely to meet existing policy targets for perception of safety, climate change and cycling mode share. Other benefits accrue from improved physical activity and air quality. The combined policy changes the shape of the cycling injury curve to significantly reduce the injury cost to increasing commuter cycling. Health benefits outweigh the costs by about 22:1 in this scenario. The model was behaviourally robust, but sensitive to assumptions about safety in numbers, the effectiveness of policies on perception of safety and the link between survey perceptions and revealed mode share.

Conclusions

This is the first time SD modelling has been used to integrate the public health outcomes of transport policy. The SD modelling process was successful in achieving agreement about the important dynamics in the commuting and public health system by a transdisciplinary group of stakeholders. I identified some pre-requisites for the successful use of participatory SD modelling in urban settings. These include a stable regional governance structure; combining regional level, spatially homogenous modelling with place-based narratives that allow stakeholders to identify with modelled relationships; the involvement of powerful policy stakeholders accompanied by the incorporation of the method into the policy process.

The cycle commuting simulation model represents the first integrated assessment of public health outcomes for specific active transport policies. It was able to demonstrate the comparative costs and benefits of policies to increase commuter cycling, identifying trade-offs between public health outcomes. Creating safe cycling infrastructure will be crucial for increasing commuter cycling. A universal approach that progressively transforms Auckland’s arterial and local roads over the next 40 years would be needed if cycling is to assist with achieving the region’s quantified sustainable transport targets. This area-wide change would be cost-effective, returning in the order of $20.00 in quantified public health benefits for every dollar spent.

The qualitative and simulation model also identify future research. The simulation of further sectors of the qualitative model would identify a wide range of other effective policy levers. Further validation of the model using time series data from other cities would strengthen the model’s validity. Well-designed studies investigating the effectiveness of specific transport interventions, and further elucidating the true effect of cycling “safety in numbers” are needed. Combining SD modelling with visioning, other kinds of transport modelling and spatial modelling could improve the public health outcomes of transport policy from high-level priority-setting through to implementation.
Acknowledgements

Firstly I extend thanks to my interdisciplinary supervisors. Professor Alistair Woodward (School of Population Health, University of Auckland) provided the opportunity to undertake this research, as well as critical guidance and epidemiological expertise. Professor Jennie Connor (Department of Preventive and Social Medicine, University of Otago) has provided longstanding public health mentorship, generous support and epidemiological expertise. Professor Karen Witten (Social and Health Outcomes Research and Evaluation, Massey University) contributed conceptual and methodological support, assistance with workshops, helpful critical discussions and warm guidance. Professor Robin Kearns (School of Environment, University of Auckland) contributed thoughtful conceptual and methodological expertise and wisdom. I also extend grateful acknowledgement to David Rees for his system dynamics modelling advice.

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The development of the simulation model involved a further group of policy stakeholders who I also acknowledge. A large number of specific methodological and data queries were enthusiastically answered to enable the modelling to occur. I am particularly grateful to Ewan Jonasen (Statistics New Zealand), Lynley Povey (Ministry of Transport), Lynette Billings (New Zealand Transport Agency), Brian Horspool (Auckland Transport), Ian Longley (National Institute for Water and Atmospheric Research), and Gerda Kuschel (Emission Impossible). For peer review I am grateful to Glen Koorey (University of Canterbury), Shane Turner at Beca (Christchurch) and James Woodcock (University of Cambridge, UK).

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Table of contents

Abstract ........................................................................................................................................... iii
Acknowledgements ........................................................................................................................ vii
Table of contents ............................................................................................................................. ix
List of Figures .................................................................................................................................. xv
List of Tables ................................................................................................................................... xix
Glossary .......................................................................................................................................... xxi
Chapter 1. Introduction .................................................................................................................... 1
  1.1. Urban commuting is an important public health problem ................................................... 1
  1.2. Theoretical perspective ......................................................................................................... 3
  1.3. Aims ....................................................................................................................................... 4
  1.4. Auckland as the research case study ..................................................................................... 5
  1.5. Thesis structure ..................................................................................................................... 7
  1.6. Roles in the project ................................................................................................................ 9
Chapter 2. Commuting is a complex public health issue ............................................................ 11
  2.1. Approach to public health ................................................................................................... 11
  2.2. The trip to work and wellbeing in cities .............................................................................. 14
    2.2.1. Physical health .............................................................................................................. 16
    2.2.2. Healthy lifestyles .......................................................................................................... 26
    2.2.3. Mental wellbeing .......................................................................................................... 35
    2.2.4. Local environmental wellbeing .................................................................................... 40
    2.2.5. Participation in society ................................................................................................. 44
    2.2.6. Biosphere ...................................................................................................................... 50
  2.3. Summary .............................................................................................................................. 53
Chapter 3. New Zealand transport planning is unlikely to achieve healthy commuting .......... 55
  3.1. Evolution of Transport policy making internationally ......................................................... 55
  3.2. Evolution of transport policy-making in New Zealand ...................................................... 60
    3.2.1. Land Transport Legislation ........................................................................................... 61
    3.2.2. New Zealand Transport Strategy (NZTS) ...................................................................... 63
    3.2.3. Auckland Regional Land Transport Strategy (ARLTS) ................................................... 69
  3.4.1. Methods .......................................................................................................................... 78
  3.4.2. Results ............................................................................................................................ 81
6.3. Cognitive mapping interviews ................................................................. 145
6.4. Development of the conceptual model.................................................... 149
   6.4.1. Workshop 1 .................................................................................... 150
   6.4.2. Workshop 2 .................................................................................... 164
   6.4.3. Meetings with the Māori Steering Group ...................................... 171
   6.4.4. Review of the causal loop diagrams with stakeholder organisations  172
6.5. Working version of the qualitative model................................................. 173
6.6. Summary................................................................................................. 181

Chapter 7. Development of the cycling simulation model.............................. 183
7.1. Overview of the simulation model structure ......................................... 184
7.2. Stock and flow structures ....................................................................... 186
   7.2.1. Commuting population ................................................................. 186
   7.2.2. Commuting mode share and vehicle kilometres travelled ............ 187
7.3. Influences on mode share ..................................................................... 190
   7.3.1. Rationale....................................................................................... 190
   7.3.2. Model structure ........................................................................... 191
   7.3.3. Parameter estimation ................................................................. 193
7.4. Cycling injury outcomes ....................................................................... 195
   7.4.1. Rationale....................................................................................... 195
   7.4.2. Model structure ........................................................................... 197
   7.4.3. Parameter estimation ................................................................. 199
7.5. Air pollution outcomes ........................................................................ 208
   7.5.1. Rationale....................................................................................... 208
   7.5.2. Model structure and parameter estimation .................................... 211
7.6. Physical activity ................................................................................... 214
   7.6.1. Rationale....................................................................................... 214
   7.6.2. Model structure ........................................................................... 216
   7.6.3. Parameter estimation ................................................................. 218
7.7. Greenhouse gas emissions ................................................................... 219
   7.7.1. Rationale....................................................................................... 219
   7.7.2. Model structure ........................................................................... 220
   7.7.3. Parameter estimation ................................................................. 221
7.8. Fuel cost savings ................................................................................. 222
   7.8.1. Rationale....................................................................................... 222
9.2.2. Data limitations ..........................................................................................................275
9.2.3. Critical reflections on the SD methodology and its use in this research ..........276
9.2.4. The study as action research ......................................................................................279
9.3. Comparison with previous and coincident research .........................................................280
9.3.1. Studies using SD modelling to integrate transport and health ..........................280
9.3.2. Other integrated assessments of transport and health ........................................280
9.4. Questions arising from the model and future research ....................................................281
9.5. Conclusions ........................................................................................................................282
9.5.1. Participatory SD modelling for integrated assessment of transport and public health ..............................283
9.5.2. Policies to increase commuter cycling .......................................................................284
Appendices ...................................................................................................................................285
Appendix A. Māori Steering Group terms of reference ........................................................287
Appendix B. Participant information sheets and consent forms ............................................289
Appendix C. Glossary of participating organisations ...........................................................297
Appendix D. Sensitivity Analysis ..............................................................................................299
Population and mode share .................................................................................................303
Air pollution outcomes .........................................................................................................307
Cyclist injury ..........................................................................................................................309
Physical activity ......................................................................................................................313
Greenhouse gas emissions ....................................................................................................314
Fuel cost savings ..................................................................................................................315
D.3 Policy parameter testing ....................................................................................................320
Infrastructure costs ...............................................................................................................320
Regional cycle network (RCN) .............................................................................................321
Arterial segregated cycle lanes (ASBL) .................................................................................322
Self explaining local roads (SER) .......................................................................................323
Mixed universal policy (ASBL + SER) .................................................................................324
Appendix E. Auckland’s planned Regional Cycle Network ..................................................327
Chapter 10. References ...........................................................................................................329
List of Figures

Figure 1-1 Population, cars and public transport use in Auckland 1925-2011 ........................................... 6
Figure 2-1. “Mandala” of health .................................................................................................................. 13
Figure 2-2 Road traffic injury crashes in the Auckland region, by time of day, day of week and by mode: all injury crashes (top), cycling (middle) and pedestrian (bottom) in 2010 ......................................... 18
Figure 2-3 Peak commuting time injury crashes as a proportion of all injury crashes 2000-2003
(Peak commuting time = Monday to Friday 6-9am and 5-7pm) ................................................................ 19
Figure 2-4 Non-linear relationship between light and moderate physical activity and the relative risk for all cause mortality .................................................................................................................. 28
Figure 2-5 Percentage median income spent on petrol in the Auckland region 2008 by
NZDep2006 decile .................................................................................................................................. 47
Figure 2-6 Pathways through which climate change affects population health ....................................... 51
Figure 3-1 Contrasting conventional transport policy-making with the OECD Environmentally Sustainable Transport (EST) approach (adapted from OECD 2002, p. 14 .............................................. 59
Figure 3-2 National Land Transport investment by activity class 2000-2010 ............................................ 67
Figure 3-3 allocation of funding by major activity class in the 2005 and 2010 Auckland Regional Land Transport Strategies ................................................................................................................................ 74
Figure 3-4 Flowchart of systematic review search results ...................................................................... 82
Figure 5-1 Generic SD modelling heuristic guide adapted from Saeed (1992) ......................................... 112
Figure 5-2 Fundamental patterns of dynamic behaviour ........................................................................ 115
Figure 5-3 Exponential growth structure ............................................................................................... 115
Figure 5-4 Goal-seeking structure ....................................................................................................... 116
Figure 5-5 Delayed balancing loop causing oscillations. Delays include (1) Measurement, perception or reporting delays, (2) decision-making delays, (3) system inertia delaying response to action ................................................................................................................................. 117
Figure 5-6 Stock and flow diagram ..................................................................................................... 117
Figure 5-7 Simple SD model diagram of population ........................................................................... 118
Figure 5-8 Iterative modelling emphasising conceptual modelling adapted from Beall and Ford (2010) ...................................................................................................................................... 121
Figure 5-9 Commuting mode share for people working in East Tamaki compared with regional mode share ............................................................................................................................................. 124
Figure 5-10 Fulfilment of roles in the study ......................................................................................... 136
Figure 6-1 2006 Census trip to work question ...................................................................................... 136
Figure 6-2 Trends in numbers of commuters and mode share for the main modes of travel to work by census year 1996-2006, in four aggregated categories ......................................................... 140
Figure 6-3 Reference mode (Desired trends are drawn from national and regional policies) .... 141
Figure 6-4 Example of an interview cognitive map ............................................................................. 146
Figure 6-5 Example of a reviewed and standardised cognitive map .................................................. 147
Figure 6-6 High level concept diagram used to describe the system ................................................... 152
Figure 6-7 High level concept diagram used to describe the public health outcomes .................... 153
Figure 6-8 Pedestrian and cyclist injury ............................................................................................ 154
Figure 6-9 Public transport services and infrastructure ....................................................................... 155
Figure 6-10 Neighbourhood sense of safety from crime ..................................................................... 156
Figure 6-11 Time, family responsibilities and accessibility of employment, goods and services 158
Figure 6-12 Workplace support ...................................................................................................... 159
Figure 6-13 Participation in urban planning and governance...................................................... 160
Figure 6-14 Environmental wellbeing, mauriora and kaitiakitanga ............................................. 161
Figure 6-15 “Car culture” and social wellbeing ............................................................................. 162
Figure 6-16 Overall preliminary model including feedback loops between sectors (high level wellbeing outcomes are shaded, main endogenous stocks are shaded) ........................................ 163
Figure 6-17 Pedestrian and cyclist injury ...................................................................................... 174
Figure 6-18 Relative attractiveness of public transport ................................................................. 175
Figure 6-19 Neighbourhood sense of safety from crime .............................................................. 176
Figure 6-20 Time pressure and accessibility of employment .......................................................... 177
Figure 6-21 Workplace support ................................................................................................... 178
Figure 6-22 Participation and leadership in transport planning ................................................... 179
Figure 6-23 Environmental and cultural wellbeing ....................................................................... 180
Figure 6-24 “Car culture” and social wellbeing ........................................................................... 181
Figure 7-1 Causal loop structure underpinning cycle commuting simulation model .................. 185
Figure 7-2 Cycling simulation model structural overview ................................................................ 185
Figure 7-3 Growth of the working population ............................................................................. 187
Figure 7-4 Commuting mode share stock and flow structure ....................................................... 188
Figure 7-5 Structure of the utility of commute modes and commute mode shares using the "market share" archetype .............................................................................................................................. 192
Figure 7-6 Cyclist injury prediction model structure ..................................................................... 198
Figure 7-7 Cycling collision rate with constant cycling numbers and changing motor vehicle numbers .................................................................................................................................................... 201
Figure 7-8 Effect on collisions of changing vehicle numbers ...................................................... 202
Figure 7-9 Simulating a postulated safety in numbers effect for Auckland ................................... 204
Figure 7-10 Effect of reported fatal injuries on cycling perception of safety ................................... 208
Figure 7-11 Structure for simulating air pollution burden of disease due to light vehicle kilometres travelled .................................................................................................................................... 212
Figure 7-12 Historical and projected trend in PM$_{10}$ light fleet emissions 2001-2030 ................... 213
Figure 7-13 Structure for the simulation of physical activity outcomes of commuter cycling .......... 217
Figure 7-14 Adjustment of expected all-cause mortality for trends in mortality over time .......... 219
Figure 7-15 Structure for the simulation of greenhouse gas emission savings ............................ 220
Figure 7-16 Trend in light vehicle CO$_{2}$eq 2001-2030 from VEPM version 4.0 ............................ 221
Figure 7-17 Structure for the simulation of fuel cost savings ....................................................... 223
Figure 7-18 Modelled trend in fuel consumption (l/km) 1991-2051 extrapolated from VEPM Version 4.0 light vehicle fleet analysis ........................................................................................................... 224
Figure 7-19 Modelled trends in petrol and diesel prices .............................................................. 224
Figure 7-20 Simulated and historical cycling commute mode share ............................................. 226
Figure 7-21 Simulated annual fatal and serious cycling injuries compared with historical data (line 2) and a linear trend in historical data (line 3) .................................................................................................................. 226
Figure 8-1 Cycle facility recommendations based on motorised traffic volume and speed: Auckland’s road classes are superimposed based on mean measured traffic counts and 85th percentile speeds .............................................................................................................................. 231
Figure 8-2 Examples of on-road cycle lanes in Auckland ............................................................ 234
Figure D-9  Effect on injury outcomes of changing the mode share threshold for the adapted safety in numbers effect from 10% to 5% for scenarios 3 (ASBL) and 5 (ASBL + SER).................. 311
Figure D-10  Effect on injury outcomes of using Jacobsen’s safety in numbers assumptions with no mode share threshold for all policy scenarios................................................................. 312
Figure D-11  Graphical functions for low, best estimate and high effects of light vehicle numbers on cyclist-vehicle collisions .................................................................................................................. 312
Figure D-12  Graphical functions for high, best estimate and low improvements in light vehicles CO2 emissions .......................................................................................................................... 314
Figure D-13  Upper and lower bounds for total CO2 emissions (megatons) from the commuting fleet under all policy scenarios ........................................................................................................ 314
Figure D-14  Upper (runs 1-5) and lower (runs 6-10) bounds for per capita CO2 emissions (tons) under all policy scenarios ............................................................................................................. 315
Figure D-15  Graphical functions for high, best estimate and low improvements in light vehicle fuel consumption .................................................................................................................. 316
Figure D-16  Total fuel cost savings for all policy scenarios under upper (top) and lower (bottom) bounds for improvements in light vehicle fuel consumption ........................................................................................................ 317
Figure D-17  Graphical functions for high, best estimate and low growth in the price of petrol and diesel ........................................................................................................................................................................ 318
Figure D-18  Total fuel cost savings (million NZ dollars) using upper (top) and lower (bottom) bounds for the growth in petrol and diesel price under all policy scenarios ........................................ 319
Figure D-19  Upper and lower bounds for cycling injury outcomes under extremes for RCN component relative risk of cycle-vehicle collision ........................................................................ 322
Figure D-20  Upper and lower bounds for cycling injury outcomes under extremes for ASBL relative risk of cycle-vehicle collision .................................................................................. 323
Figure D-21  Upper and lower bounds for cycling injury outcomes under extremes for ASBL + SER relative risks of cycle-vehicle collision and the proportion of cyclists travelling on arterial roads .......................................................................................................................... 325
Figure D-22  Range of injury outcomes for ASBL + SER policy seen under random simulation across normal distributions for the effect of components on collisions and the proportion of cyclists travelling on arterial roads .................................................................................................................................................. 326
Figure D-23  Mode share outcomes for ASBL + SER policy simulated using random sampling from normal and uniform distributions of component criteria ........................................................................ 326
List of Tables

Table 2-1 Air pollutants and their health effects ................................................................. 22
Table 2-2 Prospective cohort studies of commuting or transport-related physical activity and
primary prevention of all cause mortality, heart disease and Type 2 diabetes ................. 31
Table 3-1 Draft sustainable transport planning principles ................................................... 58
Table 3-2 Analysis of national transport strategies against OECD EST principles .......... 66
Table 3-3 Analysis of Auckland regional transport strategies against OECD EST principles ....72
Table 3-4 Summary of the validity assessment for included studies ....................... 83
Table 3-5 Characteristics and effectiveness of included studies .................................... 85
Table 5-1 Auckland Regional Land Transport Committee Membership 2008 ................ 122
Table 5-2 Summary of formal validation procedures ...................................................... 134
Table 5-3 Framework used for ethical conduct in engaging with Māori ..................... 138
Table 6-1 Groups represented in the interviews and workshops to develop the qualitative model ...................................................................................................................................................... 143
Table 6-2 Themes emerging from cognitive mapping analysis ....................................... 149
Table 7-1 Baseline stock values based on MMTW question 1991 census ..................... 188
Table 7-2 Data sources and initial values for criteria determining mode utility .......... 194
Table 7-3 Significant assumptions in the air pollution burden of disease simulation ... 210
Table 7-4 Baseline values for air pollution burden of disease per 100m light vehicle kilometres travelled .......................................................................................................................... 212
Table 7-5 All-cause mortality rates by age, gender and prioritised ethnicity per 100,000
population for the whole of New Zealand 1996-1997 .................................................. 218
Table 8-1 Classification of roads in the Auckland region with expected and measured traffic
counts and 85th percentile speeds .................................................................................... 232
Table 8-2 Proposed Auckland regional cycle network .................................................... 233
Table 8-3 The effect of self explaining roads on mode share influences .................... 247
Table 8-4 Estimated costs per km of policy interventions .......................................... 249
Table 8-5 Air pollution outcomes for scenarios for all investments in cycling infrastructure ..... 256
Table 8-6 Total cost of all scenarios to 2051 in millions of 2011 NZ dollars with different rates of escalation .......................................................................................................................... 260
Table 8-7 Summary of costs and benefits for scenarios 2-5 ....................................... 262
Table 8-8 Range of mode share and annual injury outcomes for all scenarios from the sensitivity
analysis of policy assumptions ....................................................................................... 264
Table D-1 Parameters tested in the individual sensitivity analysis ............................. 303
Table D-2 Cumulative Air pollution mortality and morbidity savings to 2051 tested against a
range of emission improvement scenarios .................................................................... 309
Table D-3 Range of all-cause mortality savings in response to variation in relative risk of all-cause
mortality due to commuter cycling ................................................................................ 313
Table D-4 Range of all-cause mortality savings in response to Uniform variation in the lead in
lead out time ..................................................................................................................... 313
Table D-5 Total cumulative greenhouse gas emissions savings from commuting to 2051 under all
scenarios ....................................................................................................................... 315
Table D-6 Sensitivity range of cumulative total fuel cost savings for all scenarios to 2051 ........ 317
Table D-7 Sensitivity range of cumulative fuel cost savings (million NZ dollars) to 2051 using upper and lower bounds for diesel and petrol price projections for all scenarios ..................... 318
Table D-8 Estimated costs per km of policy interventions ...................................................... 320
Table D-9 Sensitivity ranges for total and average annual costs of intervention policies (million NZ dollars) .................................................................................................................................... 320
Table D-10 Sensitivity ranges for all mode shares under the self explaining roads policy ........ 324
### Glossary

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
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<tbody>
<tr>
<td>95% CI</td>
<td>95% Confidence Interval</td>
</tr>
<tr>
<td>ABM</td>
<td>Agent-Based Modelling</td>
</tr>
<tr>
<td>ASBL</td>
<td>Arterial Separated Bicycle Lanes</td>
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<tr>
<td>ARLTS</td>
<td>Auckland Regional Land Transport Strategy</td>
</tr>
<tr>
<td>ARTA</td>
<td>Auckland Regional Transport Authority</td>
</tr>
<tr>
<td>BAU</td>
<td>Business As Usual</td>
</tr>
<tr>
<td>BCR</td>
<td>Benefit-Cost Ratio</td>
</tr>
<tr>
<td>CAS</td>
<td>Crash Analysis System</td>
</tr>
<tr>
<td>CBA</td>
<td>Controlled Before-and-After Study</td>
</tr>
<tr>
<td>CO</td>
<td>Carbon Monoxide</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>CO₂eq</td>
<td>Carbon Dioxide Equivalent</td>
</tr>
<tr>
<td>COPD</td>
<td>Chronic Obstructive Pulmonary Disease</td>
</tr>
<tr>
<td>CRA</td>
<td>Comparative Risk Assessment</td>
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<tr>
<td>DALY</td>
<td>Disability Adjusted Life Years</td>
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<tr>
<td>EST</td>
<td>Environmentally Sustainable Transport</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>GPS</td>
<td>Government Policy Statement</td>
</tr>
<tr>
<td>HAPiNZ</td>
<td>Health and Air Pollution in New Zealand</td>
</tr>
<tr>
<td>HIA</td>
<td>Health Impact Assessment</td>
</tr>
<tr>
<td>HRC</td>
<td>Health Research Council (of New Zealand)</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<tr>
<td>MMTW</td>
<td>Main Means of Travel to Work</td>
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<tr>
<td>NZD</td>
<td>New Zealand Dollars</td>
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<tr>
<td>LGA</td>
<td>Local Government Act</td>
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<tr>
<td>LV</td>
<td>Light Vehicle</td>
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<td>LVKT</td>
<td>Light Vehicle Kilometres Travelled</td>
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<tr>
<td>Acronym</td>
<td>Abbreviation</td>
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<tr>
<td>LTMA</td>
<td>Land Transport Management Act</td>
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<tr>
<td>LTMAA</td>
<td>Land Transport Management Amendment Act</td>
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<tr>
<td>MET</td>
<td>Metabolic Equivalent</td>
</tr>
<tr>
<td>NGO</td>
<td>Non-Government Organisation</td>
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<tr>
<td>NZDep</td>
<td>New Zealand Index of Deprivation</td>
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<tr>
<td>NZTA</td>
<td>New Zealand Transport Agency</td>
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<tr>
<td>NZTS</td>
<td>New Zealand Transport Strategy</td>
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<tr>
<td>OECD</td>
<td>Organisation for Economic Cooperation and Development</td>
</tr>
<tr>
<td>PAR</td>
<td>Participatory Action Research</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>Particulate Matter $\leq 10\mu$m in diameter</td>
</tr>
<tr>
<td>RAD</td>
<td>Restricted Activity Days</td>
</tr>
<tr>
<td>RCN</td>
<td>Regional Cycle Network</td>
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<tr>
<td>RCT</td>
<td>Randomised Controlled Trial</td>
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<tr>
<td>SD</td>
<td>System Dynamics</td>
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<td>SER</td>
<td>Self Explaining Roads</td>
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<tr>
<td>SIN</td>
<td>Safety In Numbers</td>
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<tr>
<td>UN HABITAT</td>
<td>United Nations Human Settlements Programme</td>
</tr>
<tr>
<td>VEPM 5.0</td>
<td>Vehicle Emissions Prediction Model Version 5.0</td>
</tr>
<tr>
<td>VKT</td>
<td>Vehicle Kilometres Travelled</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organization</td>
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<td>WHO HEAT</td>
<td>World Health Organization Health and Economic Assessment Tool</td>
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Chapter 1. Introduction

“The functioning of modern conurbations, with dormitories and workplaces divorced, is absolutely dependent upon an elaborate system of transport services. What has happened is that the technical possibility of carrying masses of people considerable distances to and from work has been utilised, and more or less lengthy journeys have become the daily routine of millions of workers, without much consideration given to the economic and social problems involved.”

Kate Liepmann, The Journey to Work, 1944 (p. 8)

1.1. Urban commuting is an important public health problem

Twentieth century urban development has made motor vehicles a necessary part of city life. In the context of urban design centred on automobile access and single use zoning, car use may confer health benefits through improved access to employment, health and social services and a greater variety of healthy foods. However, these benefits must be weighed against the increasing public health costs of motor vehicle dependence (Dora, 1999; Dora & Phillips, 2000; Hosking, et al., 2011), including physical inactivity, urban air pollution, road traffic injury and community severance. Together urban air pollution and traffic injuries each year account for approximately 2.5 million deaths worldwide (World Health Organization, 2008).

Widespread private motor vehicle use promotes urban planning that prioritises car access while disadvantaging other modes of transport, entrenching lifestyles that require unsustainable levels of energy consumption. This contributes significantly to climate change. Transport accounts for almost a quarter of global carbon dioxide emissions from energy use (Intergovernmental Panel on Climate Change, 2007), and is the fastest growing emissions sector (Kahn Ribeiro, et al., 2007). Climate change therefore compels us to urgently re-think transport, but it also provides an opportunity to reconsider the contribution of transport to urban public health.
Addressing the public health and environmental effects of urban car dependence requires effective action through transport policy. Although technical advances play a part, successful action needs to include reductions in the global demand for motor vehicle travel (Woodcock, et al., 2009). Recent analysis suggests that replacing motor vehicle use with active travel (such as walking or cycling) for short urban trips has the best potential for improving health and mitigating climate change (Woodcock, et al., 2009). Short, habitual urban trips to work and school are particularly suitable for public transport, walking and cycling. Generalisable transport interventions that successfully deliver the transport systems required to align climate and health objectives are urgently needed (Haines, et al., 2009). However, there is little evidence assessing the effectiveness of interventions for delivering these objectives.

Commuting comprises a special subset of urban travel. Access to employment is particularly important in allowing people to participate in society, improve their economic and social wellbeing, and afford other wellbeing enhancing goods or services. Because trips to work are short and occur at congested times, commuting contributes more heavily to the negative impacts of transport than its share of trip numbers or distance suggests. Furthermore, the short, habitual nature of urban commute trips makes them an amenable target for shifting from car dependence to other modes. As well as being habitual, people may be more likely to sacrifice vehicle travel in parts of their lives that are more “public” such as trips to work, to maintain freedoms in their private lives (for example visiting family) in the face of rising oil prices. For these reasons I have chosen to focus this study on identifying effective transport policies for changing the car dominant commuting patterns of high income cities.

Despite the special role of commuting in people’s livelihoods and wellbeing, there are no existing reviews of the effects of commuting on public health. However, there are several recent reviews that include many of the public health effects of transport more generally (Dora, 1999; Dora & Phillips, 2000; Hosking, et al., 2011; University College London Transport and Health Group, 2011). It can be concluded from these reviews that the links between commuting and health are complex and inter-related. Commuting affects all aspects consistent with a broad view of public health, including social, economic, cultural and environmental wellbeing. The reviews describe current policy approaches relevant to changing commuting patterns, including changes to infrastructure and urban land use and
programmes that aim to change the behaviour of individuals and groups. Many of these policy approaches have a scant evidence base.

Other researchers have considered how to improve transport and urban decision-making for public health and environmental sustainability (OECD Working Group on Transport, 2002; Stave, 2002; van den Belt, 2004; Woodcock, et al., 2009). They identify a need for new methodologies that enable the integration of evidence about the broad public health effects of transport, including models that can demonstrate the comparative effects of policies (OECD Working Group on Transport, 2002; Woodcock, et al., 2009). Furthermore, they suggest that greater participation in transport decision-making is likely to result in group learning leading to wider support for decisions, and therefore more successful policy implementation (OECD Working Group on Transport, 2002; Stave, 2002; van den Belt, 2004).

1.2. Theoretical perspective

The thesis is founded on the view that health, equity and sustainability are intricately linked goals, which need to be considered together to align objectives where possible and minimise trade-offs between them.

Equity and public health have been central to the concept of sustainable development since the Brundtland Report (World Commission on Environment and Development, 1987). The United Nations Human Settlements Program, UN-HABITAT, stresses the interdependence of economic and social development with environmental protection (1996) and argues for economic development that contributes to equitable improvements in quality of life, health and ecological sustainability (UN HABITAT United Nations Conference on Human Settlements, 1996). Researchers and practitioners from diverse disciplines including environmental management, environmental health and health promotion, have been converging in their approaches to urban sustainability, health and equity. Combining the conclusions of these overlapping disciplines, four principles for translating knowledge into action can be identified (Charron, 2012; De Plaen & Kilelu, 2004; Forget & Lebel, 2001; Hancock & Perkins, 1985; Labonte, 1991; Laverack, 2007; P. Newman & Kenworthy, 1999; Thompson Klein, et al., 2001; Waltner-Toews, 2001). These principles combine methodology and values, and are summarised in Box 1-1.
Chapter 1 - Introduction

Box 1-1 Principles for approaching urban sustainability

| 1. Bringing together legitimate stakeholders and transdisciplinary knowledge |
| 2. Community participation in developing questions, decision-making and citizen control of solutions |
| 3. A systems perspective placing human wellbeing within an ecosystem framework and acknowledging complexity and uncertainty |
| 4. A focus on equity and social justice |

Emerging discourses in the transport literature are likewise beginning to develop from traditional considerations of transport systems as engineered infrastructure to consider how the engineered system is connected with social and ecological systems in a complex, self-organising way (Urry, 2004), consistent with the four principles summarised above. I have therefore used these four principles to guide the aims and methodology of the thesis. The methodology considers commuting and public health to be a complex system at an aggregate regional level, but aims to elucidate the system parsimoniously to maximise group learning and policy relevance.

1.3. Aims

The thesis has four aims relating to the integration of public health knowledge to improve transport planning, and also to test a novel methodology for this purpose.

1. To develop a comprehensive conceptual model of the trip to work and public health that synthesises knowledge from epidemiology, communities and policy makers

2. To develop a commuting and public health simulation model that could quantify a range of outcomes for some particular policy options

3. To use this model to identify effective policy levers for intervening in commuting patterns to improve public health outcomes
4. To test the utility of the modelling methodology for integrating public health outcomes in a more participatory approach to transport policy making

1.4. Auckland as the research case study

Auckland is New Zealand’s largest city, with a population of about 1.5 million people. It is the fastest growing region in the country (Statistics New Zealand, 2012). A very recent multi-indicator assessment of global cities (Liu, Derudder, & Liu, 2011) classified Auckland as having lower than average GDP but very high liveability (New Zealand is a welfare state) and moderate levels of income inequality.

The city underwent a rapid period of urban growth in the mid twentieth century which coincided with the rise in dominance of the motor vehicle in many high income cities of the US, UK and Europe. A deliberate programme of motorway development and erosion of institutional support for public transport led to a low density pattern of urban growth with separated land use, or urban sprawl (Gunder, 2002; Mees & Dodson, 2006). Private motor vehicle use dominates for all travel purposes and Auckland has one of the lowest public transport patronages in the world (45 trips per capita per year in late 2011 (Auckland Transport, 2011a)). Growth in motor vehicle ownership has greatly outstripped population growth since 1920 and continues to do so. Auckland residents consistently rate traffic and poor public transport supply as an important issue detracting from quality of life in the region (Mein Consulting Ltd, 2008). Since 2000 a concerted effort by regional government to improve Auckland’s rail infrastructure and services has reversed the decline of public transport, with a steady increase in patronage over the past 11 years. Figure 1-1 summarises some of the significant historical trends and events for transport in Auckland.

New Zealand is also unusual in having fully hypothecated (specifically pre-allocated) road user charges. The hypothecated National Land Transport Fund combines fuel excise tax; diesel and heavy vehicle charges; and vehicle registration and licensing fees. Initially this fund was only spent on roads (Mees & Dodson, 2006). This was later extended to other transport projects that could be shown to benefit motorists. More recently, legislation has changed the purpose of the fund which must now contribute to a range of transport objectives (Land Transport Amendment Act, 2004). However, there remains

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1 Gross Domestic Product
significant political pressure to invest the fund in roads because motor vehicle users are the funding source (Ministry of Transport, 2009a). Other funding contributions for transport projects come from the wider national tax revenue, local government household rates and property development contributions.

Four main pieces of legislation guide land transport planning in New Zealand. All land use planning is governed by the Resource Management Act 1991, which promotes the sustainable management of natural and physical resources. The Land Transport Management Act 2003 describes the requirements for the planning, development and funding of the transport system. The Local Government Act 2002 contains requirements for local government planning, including for transport. Most recently, the Public Transport Management Act 2008 has provided regional councils with greater powers in the planning and management of public transport services.

The Ministry of Transport currently sets strategic transport policy for New Zealand and guides the allocation of funding to state highways, local roads, public transport, walking and cycling. The New Zealand Transport Agency (NZTA) is the government-owned
entity that gives effect to the national strategic direction by planning, managing and implementing transport investment. Local and regional government must also undertake planning for transport in keeping with the national strategic direction.

In Auckland, the structure of local government underwent a major transition during the research period. One regional and five local councils were combined into a single unitary Auckland Council. Strategic transport planning was retained within this new council, but some planning and all implementation is now undertaken by a Council-Controlled Organisation (Auckland Transport) governed by an appointed (rather than elected) Board.

1.5. Thesis structure

The structure and content of the next eight thesis chapters are summarised below.

Chapter 2 includes a description of the underlying theoretical approach to public health taken in the thesis. I then use this theoretical approach to guide the review of interdisciplinary literatures and synthesise evidence for the complex links between commuting and public health. I also draw some preliminary conclusions about the kind of transport policies and planning procedures that might be needed to improve the public health outcomes of commuting.

In Chapter 3 I use a sustainable transport framework to analyse New Zealand’s recent national transport legislation and strategic direction. I also assess Auckland’s most recent regional transport strategies against the same framework. These analyses illustrate the extent to which the public health considerations identified in the literature have been incorporated in national and regional transport policy. In addition, the systematic review of a case study policy in this chapter demonstrates the lack of evidence for the effectiveness of prevailing approaches to changing commuting through individual behaviour change.

The methodology for a study to improve transdisciplinary understandings of commuting and health and integrate the public health effects of a range of transport policies is described in Chapter 4. I use the principles of decision-making for urban sustainability outlined in Section 1.2 to identify participatory system dynamics (SD) modelling as a promising methodology to achieve the thesis aims.
Chapter 5 describes how I translated the previous participatory SD modelling methods described in the field of environmental management into the regional urban policy context for this thesis. I describe in detail the procedures undertaken for the modelling study, including the identification of appropriate stakeholder participants; methods used to develop the qualitative model; the methods for developing the cycle commuting simulation model; methods for identifying policies to simulate; and formal procedures used to build confidence in the validity of the model.

The iterative (involving cycles of repeated refinement) and participatory development of the qualitative model is described in Chapter 6. This chapter includes the full working version of the causal diagrams for the eight sectors that comprise the qualitative model. I also describe the decision to transition from the qualitative work to a regional cycle commuting simulation model.

In Chapter 7 I report the development of the dynamic commuter cycling simulation model based on the relevant causal diagrams from the qualitative modelling. I provide the detailed rationale and data sources for the quantification of parameters and relationships. I also report the initial validity testing of the completed simulation model.

In Chapter 8 I identify and incorporate five policy scenarios for testing using the dynamic simulation model. The policy scenarios are drawn from the existing regional transport strategy and best practice from the international literature. The scenarios are tested against relevant quantified targets from the regional transport strategy. I also report comparative effects of the scenarios on a range of other quantified public health outcomes. I summarise the resulting policy insights as well as reporting the formal sensitivity analysis of the model to its most uncertain assumptions.

The findings of the thesis are brought together in Chapter 9. As well as a summary of the main findings of the modelling and the implications for transport policy, the discussion includes reflections on the use of the participatory modelling methodology to meet the aims of the thesis. I summarise the contribution the thesis makes to existing knowledge, including similarities with, and differences from, some significant coincident studies. Finally, I summarise further research questions and potential future directions of inquiry that arise from the thesis.
1.6. Roles in the project

The research was a transdisciplinary project which I designed and led, also acting as the Principal Investigator on applications for funding. The project was funded by a project grant from the Health Research Council of New Zealand (HRC), with smaller funding contributions from the New Zealand Transport Agency and the Ministry of Health. Co-investigators on the HRC grant were Alistair Woodward\(^2\), Jennie Connor\(^3\) and Robin Kearns\(^4\). Karen Witten\(^5\) and David Rees\(^6\) were external contracted researchers on the grant. I was responsible for the initiation, design and resolution of methodological issues with the research. I also recruited and interviewed participants, facilitated the workshops and undertook all data identification, analysis and system dynamics modelling. Alistair Woodward, Jennie Connor, Karen Witten and David Rees assisted with the design of the study. Robin Kearns provided advice about implementation and qualitative methodology. Karen Witten and David Rees assisted with facilitating the modelling workshops. David Rees also provided advice about system dynamics modelling.

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Chapter 2. Commuting is a complex public health issue

In the previous chapter I introduced the importance of transport and commuting for health, equity and sustainability. I also described the aims of the thesis which are about improving understanding of the links between commuting and public health in transport planning through the development of a model that is consistent with the decision-making principles for urban sustainability summarised in Box 1-1. In this chapter I describe my theoretical approach to public health. Following this I review a wide range of disciplinary literatures to provide a broad description of the links between transport and wellbeing within an appropriate theoretical public health framework. In reviewing the cross-disciplinary transport and health literature I have drawn on commuting specific research where possible, and drawn out the relevance for commuting where I have had to summarise wider literature. Where possible I have also summarised effective methods for improving the broad public health outcomes of the transport system in the context of commuting.

2.1. Approach to public health

I have undertaken the thesis from the foundation of an ecosystem theory about public health that considers human wellbeing, ecosystem sustainability and social equity to be intertwined. This foundational approach to public health has guided the research questions, shaped the literature review and underpinned the research methodology.

Ecosystem approaches to human health represent part of an emergent paradigm for conceptualising human health, undertaking research and making policy decisions. Classical environmental health methodologies have been part of public health since its inception, with a focus on the environment as a source of hazards to human health, and an emphasis on the identification, quantification and mitigation of these hazards. In recent decades researchers and practitioners have recognised a number of limitations to this classical approach, and several factors can be identified that have converged to reshape our thinking about the complex relationships between human and ecosystem well being. Broader views of health have been developed internationally (for instance the 1986 Ottawa Charter for Health Promotion (World Health Organization, 1986)), but could also
be seen to represent a re-emergence of older understandings of human health as evidenced by the holistic understandings of health held by indigenous cultures with a continuous connection to land. In parallel with these developments in the field of health, a discourse around environmental sustainability and economic development has emerged out of our realisation of global ecological deficit, including an explicit recognition of and accounting for the fundamental services provided by the Earth’s life-support systems (Costanza, et al., 1997) as illustrated in the Millennium Ecosystem Assessment (2005).

Global environmental health problems have also highlighted the need for a more systematic approach. Addressing issues such as ozone depletion, widespread air and water pollution and global climate change requires the transcending of both national and disciplinary boundaries.

An acknowledgement that there is a two-way relationship between human health and the environment, with both hazards and benefits, also opens up exciting opportunities for intervention that can have multiple positive effects on the broader determinants of health if we can successfully achieve a transition to “health sustainability” (De Plaen & Kilelu, 2004; McMichael, 2001). An ecosystem approach to human health therefore represents both a conceptual and a methodological paradigm. Conceptually, the approach places human health in the context of the ecosystem, and seeks to comprehend the complex interactions between human wellbeing and the socio-cultural, economic and physical environments. This approach views the socioeconomic and cultural dimensions as mediators in a dynamic health-environment relationship, with an emphasis on sustainability and equity (De Plaen & Kilelu, 2004; Forget & Lebel, 2001; Waltner-Toews, 2001).

Hancock and Perkins (1993; 1985) provide a useful model for beginning to frame complex ecosystem health issues. This model is reproduced in Figure 2-1, and will be used to organise the commuting and public health literature review.

While Hancock provides a framework for considering complex public health issues, the principles for approaching urban sustainability described in Chapter 1 (Box 1-1) need to underpin ecosystem health research and practice. To achieve these goals requires a “process of enabling individuals and communities to increase control over the determinants of health and thereby improve their health” – the WHO definition of health
promotion (World Health Organization, 1986). Acting on ecosystem determinants of health reflects the Ottawa Charter’s focus on the upstream determinants of health.

![Mandala of health (Hancock, 1993)](image)

To improve health, equity and sustainability together in New Zealand, indigenous Māori views of wellbeing and health promotion also need to be embedded in our thinking and practice. This recognises that public health action in New Zealand is carried out in the context of the Treaty of Waitangi relationship between Tangata Whenua (Māori) and the Crown, as well as the importance of addressing inequalities in wellbeing for Māori (Reid, 1999). One of the initial purposes of the Treaty was to protect the wellbeing of Māori (Reid & Cram, 2005), and the three Articles can be seen as central to wellbeing, especially when the Māori language version of the Treaty is used (Linderfalk, 2007): Kawanatanga (governance), Tino Rangatiratanga (self determination), and Oritetanga (equity) (A Treaty Understanding of Hauora in Aotearoa-New Zealand TUHA-NZ, 2002). Explicit links between these principles and health promotion practice (TUHA-NZ, 2002) emphasise participation and equity, and have overlapping themes with the ecosystem approach described above.
A process of re-examining, re-affirming and promoting Māori models of wellbeing and health promotion has occurred during recent decades (Durie, 1999; Pere, 1991), and concepts of environmental wellbeing can be found in many of these models. These concepts include waiora (the importance of fresh water, and more widely a healthy environment); whenua (the land, the placenta); turangawaewae (standing place); and mauri (life force, energy, interconnectedness) (Palmer, 2004). They encompass aspects of ownership of, access to and responsibility for the land, as well as the health of the natural world and sustainable resource management. The Te Pae Mahutonga model of health promotion (Durie, 1999) combines goals for wellbeing of Mauriora (access to a secure cultural identity), Waiora (environmental protection), Toiora (healthy lifestyles) and Te Oranga (participation in society and access to services). Durie also identifies two important process requisites for meeting these goals: Ngi Manukura (leadership) and Te Mana Whakahaere (autonomy). He argues that the goals and process requirements are not just relevant for Māori but for the whole New Zealand population. This health promotion model closely reflects the framework and principles for ecosystem health from an indigenous perspective. I therefore combine these two frameworks (Hancock’s ecosystem health framework and Te Pae Mahutonga) in considering the literature about urban commuting and health.

2.2. The trip to work and wellbeing in cities

Modern urban transport systems have been vital in allowing people to access employment, education, goods and services. The current motor vehicle oriented design of many modern cities has meant that car ownership confers health and social benefits. Car use in the trip to work in such cities allows access to employment, education and training that would not otherwise occur, including access to the labour force for many people while meeting other responsibilities within a set of time, space and structural constraints (P. Jones, 2011; Lucas & Jones, 2009). These responsibilities often include getting children safely to school and other chosen activities, managing family healthcare, provisioning the household and caring for elders. However, a reliance on car ownership and use for accessing employment while managing other constraints also has significant negative effects on public health, not just for the individuals involved in commuting to work by car but also for the wider community. Furthermore, reliance on motor vehicle
transport contributes to the current serious climate change threat to the biosphere, compromising the ability of the earth to sustain healthy human life.

The trip to work is an important part of the lives of almost all urban adults. Journeys to work tend to be short, follow habitual patterns within a city, and contribute significantly to overall vehicle trips and health outcomes. Commuting within cities involves large numbers of people using patterned routes. These provide economies of scale that make investment and use of public transport a viable option. The short distance of many commute trips also makes walking and cycling possible. All these characteristics mean commuting is a potentially powerful focus for change that could successfully retain the benefits of current car use patterns while lessening the negative impacts.

Much of the academic discussion around the links between transport and health has focused on the impacts on physical wellbeing through air pollution, injury and physical activity. However, there are broader implications of transport choices on mental, social, environmental and economic aspects of wellbeing, as well as the unequal distribution of wellbeing by gender, socioeconomic status, and ethnicity. The dearth of evidence about the wider impacts of transport behaviours is one reason for the very limited ways that public health is included in transport policy discussions (Dora & Phillips, 2000).

Using both Hancock’s ecosystem health model and Te Pae Mahutonga as frameworks, in the following section I review the literature about the links between urban journeys to work and public health in a context of car-dominant urban design. International evidence is discussed, as well as New Zealand specific evidence where it is available. Up-to-date and comprehensive systematic reviews are readily available for air pollution, physical activity and injury within the health literature. For other links, I have widely reviewed the health, environmental science, transport, urban design, planning and social science literatures to synthesise the existing evidence. Where possible I have also included evidence about the effectiveness of interventions, particularly focusing on recommendations for transport policy. In reviewing the literature I have used the terms “commuting” and the “trip to work” to cover trips to and from work, adult education and training in an urban setting. The review is structured to move from the centre towards the outer circles of Hancock’s ecosystem health model.
2.2.1. Physical health

This section includes the most studied connections between transport and health in the public health literature, and includes a great deal of research from an epidemiological perspective on road traffic injury and the physical health effects of air pollution.

Road traffic injury

Injury is the most comprehensively studied health impact of transport, and features prominently in prevention programmes and policy. Road injuries are among the leading causes of mortality and morbidity worldwide. Road traffic crashes were responsible for 2.7% of the global burden of mortality and morbidity in 2004, with significant inequalities between high, middle and low-income countries (World Health Organization, 2008). Rapid economic development and urbanisation without specific policies to achieve a successful environmental health risk transition led to a substantial road traffic injury burden in middle income countries in particular (Dora & Phillips, 2000; Kjellstrom & Rosenstock, 1990). If current global trends continue, road traffic injury will comprise a greater proportion of the global burden of disease and disability in coming decades (Peden, McGee, & Sharma, 2002). The risk of road traffic injury differs by mode. Although car drivers and passengers comprise the greatest proportion of road injuries and deaths in developed countries, the risk of injury per trip or per distance travelled is greatest for motorcyclists, cyclists and pedestrians, whereas public transport (rail and bus) is the safest ways to travel (Dora & Phillips, 2000).

In developed countries, mortality rates from road traffic injuries have declined over the last forty years (Peden, et al., 2004), despite large increases in the rate of car ownership and vehicle kilometres travelled (Banister, 2005). This has been the result of a range of safety-oriented and other regulatory, engineering and technological improvements. However, there is evidence that these declines have begun to stabilise in many developed countries, despite ongoing road safety interventions (World Health Organization, 2009a). In addition, the trends in non-fatal road traffic injuries are not so clear, as these injuries are more difficult to measure and report consistently. Some road safety interventions prevent exposure to injury risk altogether (e.g. reductions in motor vehicle use and separation of vulnerable road users), others reduce both exposure to and severity of risk (e.g. motor vehicle speed reductions), and others only reduce the severity of the impact of injuries (e.g. seatbelt and helmet laws). Reducing the severity of injuries alone may
reduce mortality while increasing or maintaining a largely hidden burden of disability and health service costs (World Health Organization, 2009a).

In New Zealand, and in the Auckland region particularly, road traffic injury is a major cause of mortality and morbidity, and New Zealand has a high rate of road traffic fatalities compared with other OECD countries (Connor, Langley, & Cryer, 2006). As in other high income countries, the number of road traffic fatalities has reduced by more than 40% over the past 30 years despite increases in population and per capita car ownership. New Zealand’s high rate of fatal road crashes is considered to be partly due to its very high level of per capita car ownership (Connor, et al., 2006). A further contributing factor is likely to be the persistently high level of speeding despite speed restrictions. Auckland in particular has high urban unimpeded speeds that have not reduced over time. Although urban roads have a posted speed limit of 40 to 50kph, 2010 mean speeds on Auckland’s urban roads were 55kph, while 85th percentile speeds remain at about 60kph (Ministry of Transport, 2011a). Most recent trend data about fatal and serious road traffic injury in New Zealand suggests that the decline in age adjusted fatality rates has begun to flatten out, and age adjusted serious injury rates are stable or increasing (Ministry of Transport, 2011a).

Significant inequities in road traffic injury are also evident in New Zealand. A cohort study of Auckland adults (Whitlock, et al., 2003) found a gradient in driver injury risk by both occupational status and level of education, with the lowest quartile of occupational status experiencing four times the risk of driver injury as the highest quartile. Administrative injury statistics (Ministry of Transport, 2011a) also suggest inequities for Māori, who comprise 15% of the population but over 30% of road traffic fatalities in 2010. Epidemiological studies focusing specifically on children have also found gradients by socioeconomic status and inequities for Māori and Pacific children (Roberts, Norton, Jackson, Dunn, & Hassall, 1995; Shaw, Blakely, Crampton, & Atkinson, 2005). Child pedestrian injury is the most important contributor to these inequities, with higher neighbourhood traffic volumes and speeds playing a significant role (Roberts, et al., 1995).

Specific information about the link between injury and the trip to work is sparse. However, analysis of road traffic injury by time of day suggests that commuting contributes significantly to overall crashes. Figure 2-2 demonstrates the commute time
peaks in fatal and serious injury crashes for all injury crashes, cycling and pedestrians. All three graphs demonstrate the same pattern, although commute time peaks are most stark for cyclist injuries.

Figure 2-2 Road traffic injury crashes in the Auckland region, by time of day, day of week and by mode: all injury crashes (top), cycling (middle) and pedestrian (bottom) in 2010 (Ministry of Transport, 2011a)
Figure 2-3 also suggests that commuting is making up an increasing proportion of total serious road traffic injuries over time, although there is no such pattern for fatal injuries.

Commuting related road traffic injury is inconsistently included with injury as part of occupational driving (such as taxi driving, courier travel or truck driving), or as part of occupational injury as a whole (Driscoll, Takala, Steenland, Corvalan, & Fingerhut, 2005). Unusually, Australia and New Zealand have both counted commuting related injuries separately in assessments of occupational injury (Driscoll, et al., 2004; McNoe, Langley, & Feyer, 2005; R. Mitchell, Driscoll, & Healey, 2004). In Australia, R. Mitchell, Driscoll and Healey (2004) counted both commuter deaths and the deaths of bystanders from commuter crashes between 1989 and 1992. They counted 684 such fatalities, comprising 7.4% of all road traffic deaths in that period. The Auckland Car Crash Injury Study (Connor, et al., 2002) recorded this information for all drivers in serious crashes in 1998-9 in the Auckland region. The authors found that 15% of drivers in crashes that resulted in hospitalisation or death were commuting, and another 5% were working at the time (unpublished data). Although these figures give an indication of the contribution made by commuting to overall road traffic injury, they do not include the wider community burden of injury caused by commuting.
Policy interventions that have been shown to be effective at reducing road traffic injury mortality include the following (Dora & Phillips, 2000; Peden, et al., 2004):

1. Enforced blood alcohol limits
2. Policies that increase the use of seatbelts, motorcycle and bicycle helmets
3. Interventions to improve the safety of vehicle design
4. Enforced lower speed limits

Reducing vehicle speeds is particularly important for transport policy as it is likely to have a broader positive impact on transport-related wellbeing, including reduced fuel consumption, air pollution and noise levels. In the case of injury, reducing vehicle speeds can reduce both the risk of traffic crashes and the severity of crashes when they occur (Aarts & van Schagen, 2006). The review of systematic reviews by Morrison, Petticrew and Thomson (2003) about the effectiveness of transport interventions for improving health found that traffic calming schemes were among the most effective interventions and that they successfully reduced speed and vehicle numbers on residential streets. A systematic review of traffic calming (measures that reduce vehicle speeds and vehicle volumes) in Europe and Australia was first undertaken by Bunn, et al. in 2003 and updated in 2009 (Bunn, et al., 2003). All studies were controlled before-and-after studies demonstrating a consistent reduction in road user deaths of approximately 20% and a consistent reduction in injury rates of approximately 15%. A recent time series analysis of the introduction of 20mph (32 kph) speed limits in London, UK (Grundy, 2009) provides further empirical evidence of the effectiveness of reducing vehicle speeds. The low speed zones were thought to reduce average vehicle speed from 42 kph to 27 kph, resulting in an estimated 42% reduction in all injuries, a 32% reduction in pedestrian injuries and a 17% reduction in cyclist injuries.

There is also an established non-linear relationship between the number of vehicles on the road and the road traffic injury rate, with a reduction in motor vehicle injury seen over time despite a marked increase in the number of cars (Smeed’s Law (I. Smith, 1997)). Conversely, it is also evident that at busy times the likelihood of road traffic injury is greatest (scale effect (Elvik, Høye, Vaa, & Sørensen, 2009, pp. 53-56)) and that increasing numbers of motor vehicles leads to increasing rates of injury for other road users, especially pedestrians and cyclists (Bhalla, Ezzati, Mahal, Salomon, & Reich, 2007). It is therefore likely that decreasing the number of cars on the road, combined with
continuing attention to other aspects of road safety, would have a positive impact on injury rates for car users, pedestrians and cyclists. However, caution is needed when considering the risk of injury to pedestrians and cyclists, since there is also likely to be a complex relationship between the number of pedestrians and cyclists and injury rates, with the risk of a substitution effect to more vulnerable modes of transport. It is likely that Smeed’s Law (decreasing rates of injury with increasing numbers of mode users) applies to pedestrians and cyclists as well as motor vehicles. For instance in OECD countries with the highest numbers of unprotected road users (such as Denmark and Holland) cyclists and pedestrians have the lowest injury rates per distance travelled (Jacobsen, 2003; Pucher & Buehler, 2008).

Air pollution

Epidemiological evidence over the last half century has consistently demonstrated the harmful effects of outdoor air pollution from transport exhaust emissions, with both short and long-term effects on cardiovascular and respiratory function (Brunekreef & Holgate, 2002; Krzyzanowski, Kuna-Dibbert, & Schneider, 2005; Ren & Tong, 2008; Schwartz, 1994). In European cities the contribution of motor vehicle combustion of petrol and diesel fuels to overall air pollution has been estimated at about 40% of the fine particulates, 75% of the nitrous oxides and all of the carbon monoxide (Dora & Phillips, 2000). The spatial distribution of vehicle emissions at low altitude in areas with high population concentration increases their impact on human health. Vehicles emit a complex cocktail of pollutants from exhaust and from wear of other vehicle parts such as tyres and upholstery. These pollutants include fine particulates; oxides of sulphur, nitrogen and carbon; lead; volatile organic compounds (VOCs) such as benzene; and heavy metals such as mercury and chromium. The evidence for the health effects of these pollutants comes from a combination of animal and human experimental studies, time series epidemiological analyses of monitored air quality, cohort studies and cross-sectional studies (Krzyzanowski, et al., 2005). Taking the evidence together, it is likely that transport-related air pollution affects a number of different health outcomes. Table 2-1 summarises the current state of the evidence from both epidemiology and toxicology. Studies of the health effects of particular components of vehicle exhaust do not account for the additive or multiplicative effects of pollutants in combination, for example the effect of fine particulates coated with oxides of nitrogen and sulphur on delivery of these oxides to lung tissue, or the sensitization effect of carbon monoxide on heart tissue which
may potentiate the effect of small particles on cardiovascular function (HEI Panel on the Health Effects of Traffic-Related Air Pollution [HEI Panel, 2010]).

The strongest evidence for a causative effect is for the exacerbation of asthma symptoms in children. However, there is a growing body evidence to suggest that traffic related air pollution is enough of a public health concern to deserve a policy response, particularly given the large numbers of people living and travelling in significant exposure zones (considered to be within 300 to 500m of a main road) (HEI Panel, 2010). There is also emerging evidence that the mortality and morbidity effects of motor vehicle related air pollution are greater than that from other sources such as wood smoke (Laden, Neas, Dockery, & Schwartz, 2000).

<table>
<thead>
<tr>
<th>Health outcome</th>
<th>Pollutant</th>
<th>Type of evidence</th>
<th>Strength of evidence for a causative association (HEI Panel, 2010)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortality</td>
<td>Black smoke</td>
<td>O</td>
<td>Suggestive but not sufficient</td>
</tr>
<tr>
<td></td>
<td>Ozone</td>
<td>O, E</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fine particulates</td>
<td>O, E</td>
<td></td>
</tr>
<tr>
<td>Non-allergic respiratory</td>
<td>Black smoke</td>
<td>O</td>
<td>Suggestive but not sufficient</td>
</tr>
<tr>
<td>disease</td>
<td>Ozone</td>
<td>O, E</td>
<td>(pulmonary function)</td>
</tr>
<tr>
<td></td>
<td>Nitrogen dioxide</td>
<td>O, E</td>
<td>Inadequate and insufficient (COPD)</td>
</tr>
<tr>
<td></td>
<td>VOCs</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Diesel</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>Allergic respiratory</td>
<td>Ozone</td>
<td>O</td>
<td>Sufficient (exacerbation of asthma in children)</td>
</tr>
<tr>
<td>disease</td>
<td>VOCs</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nitrogen Dioxide</td>
<td>O, E</td>
<td>Sufficient or suggestive (asthma prevalence/incidence in children)</td>
</tr>
<tr>
<td></td>
<td>Particulates</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Diesel</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>Cardiovascular disease</td>
<td>Black smoke</td>
<td>O</td>
<td>Suggestive but not sufficient</td>
</tr>
<tr>
<td>Cancer</td>
<td>Nitrogen dioxide</td>
<td>O, E</td>
<td>Inadequate and insufficient (Experimental toxicological studies provide stronger evidence)</td>
</tr>
<tr>
<td></td>
<td>Diesel</td>
<td>O, E</td>
<td></td>
</tr>
<tr>
<td></td>
<td>VOCs</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>Reproductive outcomes</td>
<td>Nitrogen dioxide</td>
<td>O</td>
<td>Inadequate and insufficient</td>
</tr>
<tr>
<td></td>
<td>Carbon monoxide</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sulphur dioxide</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Particulates</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Diesel</td>
<td>E</td>
<td></td>
</tr>
</tbody>
</table>

Table 2-1 Air pollutants and their health effects (adapted from Krzyzanowski, et al., 2005). Evidence about the strength of evidence summarises the HEI Panel on the Health Effects of Traffic-related Air Pollution (2010). O: Observational studies, E: Experimental studies.
Our understanding of the health burden of traffic related air pollution is constrained by a number of factors, including the use of individual components of exhaust (usually particulates or nitrogen dioxide) as a surrogate for traffic related air pollution, and the use of ambient air quality monitoring as a surrogate for individual exposure measurements, with the attendant assumption that people experience most of their exposure at their place of residence (Fisher, et al., 2007; HEI Panel, 2010; Krzyzanowski, et al., 2005; Ren & Tong, 2008). Geospatial mapping of exposure also tends to make assumptions about a gradient in exposure with distance of residence from main roads (Brunekreef & Holgate, 2002).

Much less is known about the specific contribution journeys to work make to air pollution exposure, either for commuters themselves, or for the wider community. Some inferences can be made about the contribution of commuting in different cities through travel surveys of the proportion of all urban trips contributed by commuters, however commuting is likely to play a more heavily weighted role in the amount of emissions and the number of people exposed for three reasons. Firstly, at peak commute times there is a potent combination of the highest concentration of people exposed to the highest levels of emissions (within 500m of arterial roads). Although this exposed population includes a large group of healthy workers (who are likely to be less sensitive to the health effects of air pollution) it also includes large numbers of children “commuting” to school, a highly sensitive exposure group. Secondly, at peak times traffic is at its most congested, with frequent stops and starts at low average speed. These driving conditions can increase emissions by up to 1.74 times free-flowing urban levels (André & Rapone, 2009). Thirdly, the highest emissions occur in the first ten minutes of any trip – the cold start effect (Favez, Weilenmann, & Stilli, 2009; Krzyzanowski, et al., 2005). Commute trips tend to be short (about half of Auckland commutes are under 5km (Goodyear & Ralphs, 2009)) and the cold start effect therefore contributes a greater proportion of these trips.

Exposure to vehicle exhaust pollutants varies with commute mode. This is important since perceived air quality may influence mode choices, with an assumption that vehicles protect occupants from exposure. A growing number of studies have compared exposure between modes for commuters, particularly between car occupants, pedestrians and cyclists. Although levels of all pollutants tend to be higher in vehicles than by the roadside (de Hartog, Boogaard, Nijland, & Hoek, 2010; HEI Panel, 2010), very few studies have accounted for differences in minute ventilation (the volume of air breathed
per minute) due to physical exertion or differences in the duration of trips and therefore exposure (de Hartog, et al., 2010). Studies that have attempted to account for physical exertion when comparing cycling with motorised modes have found that exposure to ultrafine particles and volatile organic compounds are comparable or higher for cyclists (Bernmark, Wiktorin, Svartengren, Lewne, & Aberg, 2006; O'Donoghue, Gill, McKeivit, & Broderick, 2007), but that exposure levels are sensitive to even small differences in the distance from traffic, and the position of cyclists at intersections (Kaur, Nieuwenhuijsen, & Colvile, 2007).

Studies that have included public transport modes have shown pollutant levels to be comparable to cars, but this depends heavily on the age of vehicles, the level of self pollution (for example through ventilation) and the pollutant being measured (Kingham, Pattinson, Shrestha, Longley, & Salmond, 2011).

New Zealand’s small population, low density cities, geographical isolation and meteorological patterns all contribute fortuitously to relatively good air quality. Despite this, there is significant mortality and morbidity associated with air pollution. The most recent and comprehensive study of the health burden of air pollution is the *Health and Air Pollution in New Zealand* (HAPiNZ) study completed by Fisher, et al. in 2007 (although this study is currently being updated). The HAPiNZ study combined surrogate estimates of exposure from vehicle kilometres travelled, meteorological data and spatial mapping (Kingham, Fisher, Hales, Wilson, & Bartie, 2007) with the effect estimates from cohort studies. The authors modelled the effects of particulates less than 10\(\mu\)m (PM\(_{10}\)) on adults over 30 using mortality risks derived from dose response relationships from two large longitudinal studies in the US (Dockery, et al., 1993; Künzli, et al., 2000; Pope III, et al., 1995) as well as morbidity dose responses for respiratory admissions to hospital. They assumed no difference in effect on morbidity or mortality between motor vehicle exposures and other sources, but PM\(_{10}\) exposure estimates for all urban census area units in New Zealand were calculated separately by source. Particulate vehicle emissions were estimated to cause 414 deaths per year in New Zealand (about half of the total air pollution mortality) and about 670,000 restricted activity days. The HAPiNZ study also estimated admissions to hospital due to carbon monoxide exposure from motor vehicles, concluding that this caused approximately 790 hospital admissions.
A number of studies in the past decade have examined inequalities in exposure to air pollution using spatial methods, to assess the importance of air pollution as an environmental justice issue. G. Mitchell and Dorling (2003) reviewed the results of such studies undertaken in the UK examining both socioeconomic and ethnic disparities in air pollution exposure. Ten city wide and regional studies found inconsistent results because of small sample sizes, and poor study quality. The authors’ own national study found a J-shaped relationship between neighbourhood deprivation and mean annual nitrogen dioxide exposure, and a linear but inverse relationship between levels of car ownership and pollution – those wards with lowest levels of car ownership had the highest levels of pollution, suggesting that the poorest households contribute least to air pollution, but carry the heaviest burden. The J-shaped relationship between air pollution and deprivation has been emulated more recently in a further England-wide study using multiple measures of deprivation and multiple measures of air pollution (Briggs, Abellan, & Fecht, 2008). Other studies from the US (Green, Smorodinsky, Kim, McLaughlin, & Ostro, 2004; Gunier, Hertz, Von Behren, & Reynolds, 2003) have demonstrated socioeconomic gradients and ethnic disparities in air pollution exposure in children using proximity to busy roads, and traffic density as surrogates for air pollution exposure. Jacobsen, Hengartner and Louis (2005) used multiple analytic approaches to explore the links between ethnicity, socioeconomic status and proximity to highways in New York. They found that interactions between ethnicity and poverty were more important predictors of exposure than each alone. They also highlighted that there are likely to be trade-offs between benefits of accessibility and exposure to harms in proximity to highways.

In New Zealand, Kingham, Pearce and Zawar-Reza (2007) have undertaken a similar study to G. Mitchell and Dorling’s, investigating the association of neighbourhood deprivation and ethnicity in Christchurch with simulated levels of PM$_{10}$ from motor vehicle emissions. They also found a J-shaped relationship between PM$_{10}$ and small area deprivation level (as measured by the New Zealand Deprivation Index 2001), with levels twice as high in the most deprived compared with the least deprived quintile. An inverse relationship between car ownership and exposure was also evident. The same study suggested emerging evidence for increased exposure to particulate air pollution for Māori, Pacific and Asian people (Pearce, Kingham, & Zawar-Reza, 2006), although a national version of the study (Pearce & Kingham, 2008) failed to confirm this association. In addition to potential disparities in exposure, there are likely to be disparities in the effects
of air pollution on mortality and morbidity. In their recent New Zealand cohort study, Hales, Blakely and Woodward (2010) found stronger effects of PM$_{10}$ on Māori all-cause mortality (a 20% increase in all-cause mortality for every 10μg/m$^3$ increase in PM$_{10}$, compared with 7% for New Zealand Europeans), that could be explained by differences in the prevalence of other risk factors (such as smoking), other co-morbidities (such as asthma), or differences in the kind of air pollution dominating the exposures.

There is a range of suggested transport policy measures designed to reduce vehicle-related air pollution exposure. To date, policy responses have focused heavily on technological improvements to vehicles, such as improving engine efficiency, introducing cleaner fuels and catalytic converters that remove pollutants at the exhaust pipe. These interventions have tended to be a response to the introduction of regulatory standards for specific pollutants, and sometimes decrease one pollutant while increasing the emission of others (HEI Panel, 2010). There is increasing acknowledgement that technological improvements will not be sufficient as the demand for vehicle use grows with population growth and increasing travel per person (Dora & Phillips, 2000). In addition, further technological improvements to vehicle emissions are likely to achieve smaller gains at higher cost (Brunekreef & Holgate, 2002). Transport and land use policies that reduce the number of vehicle kilometres travelled will also be required if air pollution related mortality and morbidity is to be reduced (Fisher, et al., 2007). For example, the London Congestion Charge, which has reduced vehicle numbers in the centre of London, has improved air quality morbidity and mortality, with air quality improvements greatest in areas of high deprivation (Tonne, Beevers, Armstrong, Kelly, & Wilkinson, 2008). The more recent comparisons of exposure to air pollutants between different transport modes also suggest that separating cyclists from traffic and ensuring clean public transport vehicles are interventions that would maximise the public health benefits of these modes while minimising harms.

2.2.2. Healthy lifestyles

This section links personal behaviour with the psycho-socioeconomic environment in Hancock’s ecosystem health model, and fits with toiora in Te Pae Mahutonga. The most significant link between commuting and healthy lifestyles relates to people’s ability to sustain adequate levels of physical activity for health. The research about physical activity, commuting and health is also drawn from the epidemiological literature.
There is a growing body of research examining whether changing the mode of travel to work to more active transport has a direct health benefit through increasing physical activity. The evidence we have to date about the link between physical activity and health suggests strongly that there are significant potential benefits.

A causal link between physical inactivity and all-cause mortality, as well as a number of specific diseases and risk factors, is considered irrefutable (Warburton, Nicol, & Bredin, 2006). Regular physical activity is preventive in cardiovascular disease, diabetes, cancer, hypertension, obesity, depression and osteoporosis (Warburton, et al., 2006). There have been two major systematic reviews and meta-analyses of physical activity, all-cause mortality and cardiovascular mortality. Nocon, et al.(2008) pooled results from 900,000 participants of large cohort studies and reported marked decreases in risk between the highest and lowest physical activity categories. Pooled risk reductions were 35% for cardiovascular mortality and 33% for all-cause mortality. However, these risk reductions apply to the fittest group, and therefore do not reflect the protective effect of moderate physical activity. A more recent systematic review and meta-analysis of cohort studies (Woodcock, Franco, Orsini, & Roberts, 2011) focused specifically on light and moderate physical activity. Compared with no activity the authors found that 2.5 hrs of brisk walking per week reduced all cause mortality by approximately 10% (95% CI 4-18%), whereas the effects of cycling were mixed. This review was also able to explore the nature of the dose-response relationship between light and moderate physical activity and all-cause mortality, finding that a power function best described the non-linear relationship (Figure 2-4).
Several prospective cohort studies have specifically investigated the health benefits of active commuting, albeit through self-reported levels of walking and cycling. I describe the design of those studies that adjusted for other kinds of physical activity in their analysis in detail below and the results of all these studies are summarised in Table 2-2.

In an analysis of the Osaka Health Survey in Japan, Hayashi and Tsumura (1999) analysed the effect of walking to work on the incidence of hypertension for just over 6000 male employees of a gas company, followed up for an average of a decade. Controlling for a range of confounders including leisure-time physical activity, they found that every extra 10-minutes of walking to work conferred a 12% reduction in hypertension incidence. Andersen, Schnor, Schroll and Hein (2000) investigated the effects of different types of physical activity on all-cause mortality in a number of Copenhagen cohorts including over 30,000 participants. Cycling was the only mode of transport considered in the analysis. The relative risk of an average of 3 hours per week spent cycling to work compared with not cycling to work was adjusted for leisure time physical activity. Over the succeeding decade Hu and colleagues (2004; 2007; 2003) have published a number of reports on a large prospective cohort study of middle-aged Finns further investigating the
relative benefits of leisure time, occupational and commuting physical activity in the primary and secondary prevention of diabetes and heart disease. Information about commuting physical activity included walking or cycling to work, which were grouped together. Hazards ratios were adjusted for age, risk factors for diabetes, as well as heart disease and other types of physical activity.

Other prospective studies have examined the effects of walking and cycling for transportation (“active transport” including work and other utility purposes). A very large cohort study in Shanghai, China (Matthews, et al., 2007) included the effects of active transport on all-cause, cardiovascular and cancer mortality in women. The follow up of more than 67,000 women was short, and relative risk calculations were adjusted for social and risk factor confounders, as well as other kinds of physical activity. Besson, et al. (2008) analysed the effects of active transport on all-cause and cardiovascular mortality for a cohort of older men and women in the UK. Information about different types of physical activity for the previous year was collected at the start and the analysis included an average of 7 years follow up. Hazards ratios were adjusted for age, sex, cardiovascular risk factors and other types of physical activity. This study included very few people who cycled for transport (61 who cycled over 30 minutes/week).
<table>
<thead>
<tr>
<th>Study</th>
<th>Exposure</th>
<th>Outcome measure</th>
<th>Mean Follow-up</th>
<th>Risk ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hayashi and Tamura 1999</td>
<td>Walking to work in mins per trip</td>
<td>Hypertension in men</td>
<td>10 years</td>
<td>♂ 1.0</td>
</tr>
<tr>
<td></td>
<td>0-10</td>
<td></td>
<td></td>
<td>♂ 0.88 (0.77-1.08)</td>
</tr>
<tr>
<td></td>
<td>11-20</td>
<td></td>
<td></td>
<td>♂ 0.71 (0.59-0.95)</td>
</tr>
<tr>
<td></td>
<td>≥ 21</td>
<td></td>
<td></td>
<td>♂ 0.88 (0.78-0.98)</td>
</tr>
<tr>
<td>Anderson, et al. 2000</td>
<td>Cycling an average of 3 hours/week</td>
<td>All-cause mortality</td>
<td>14.5 years</td>
<td>0.72 (0.57-0.91)</td>
</tr>
<tr>
<td>Hu, et al. 2003</td>
<td>Cycling and walking to work 1-29 mins per trip</td>
<td>Type 2 diabetes incidence</td>
<td>12 years</td>
<td>0.96 (0.74-1.25)</td>
</tr>
<tr>
<td></td>
<td>Cycling and walking to work &gt; 30mins per trip</td>
<td></td>
<td></td>
<td>0.64 (0.45-0.92)</td>
</tr>
<tr>
<td>Hu, et al. 2007</td>
<td>Cycling and walking to work 1-29 mins per trip</td>
<td>Hospitalised Myocardial infarction and fatal coronary heart disease</td>
<td>18.9 years</td>
<td>♂ 0.99 (0.91-1.08)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>♂ 0.95 (0.83-1.08)</td>
</tr>
<tr>
<td></td>
<td>Cycling and walking to work &gt; 30mins per trip</td>
<td></td>
<td></td>
<td>♂ 0.99 (0.90-1.10)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>♂ 0.80 (0.69-0.92)</td>
</tr>
<tr>
<td>Matthews, et al. 2007</td>
<td>Walking for transportation in MET-hours/day</td>
<td>All-cause mortality</td>
<td>5.7 years</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0-3.4</td>
<td></td>
<td></td>
<td>0.94 (0.81, 1.09)</td>
</tr>
<tr>
<td></td>
<td>3.5-7</td>
<td></td>
<td></td>
<td>0.83 (0.69, 1.00)</td>
</tr>
<tr>
<td></td>
<td>7.1-10</td>
<td></td>
<td></td>
<td>0.86 (0.71, 1.05)</td>
</tr>
<tr>
<td>Study</td>
<td>Exposure</td>
<td>Outcome measure</td>
<td>Mean Follow-up</td>
<td>Risk ratio (95% CI)</td>
</tr>
<tr>
<td>-------</td>
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<td>----------------</td>
<td>-------------------</td>
</tr>
<tr>
<td></td>
<td>Cycling for transportation in MET-hours/day</td>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.1-3.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>≥ 3.5</td>
<td></td>
</tr>
<tr>
<td>Besson, et al. 2008</td>
<td>Walking for transportation in mins/week</td>
<td>All-cause mortality</td>
<td>7 years</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>≤ 90</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&gt; 90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cycling for transportation in mins/week</td>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>≤ 30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&gt; 30</td>
<td></td>
</tr>
</tbody>
</table>

Table 2-2 Prospective cohort studies of commuting or transport-related physical activity and primary prevention of all cause mortality, heart disease and Type 2 diabetes

In a contrasting study design, Wennberg, et al. (2006) reported a nested case-control study of physical activity from Sweden. The commuting behaviour of cases of 581 people with first myocardial infarction was compared with a group of population-based controls. Commuting behaviour was divided into car use versus other modes, which included bus, walking and cycling. Using a car every season for the trip to work was associated with an odds ratio of first MI of 1.71 (95% CI 1.17-2.66). This increased risk may have been due to the physical activity associated with other modes, but it could also be explained by other risk factors associated with driving such as stress or eating behaviours. Many of
these studies were included in a meta-analysis by Hamer and Yoichi (2008) who combined the effects of walking and cycling to calculate an integrated relative risk of 0.89 (0.81-0.98) combined “cardiovascular outcomes” of any active commuting.

In summary, almost all these prospective studies indicate that walking or cycling to work has a likely beneficial effect on health even after adjusting for other kinds of physical exercise. Although a large proportion of the all cause mortality benefit is mediated by the primary prevention of cardiovascular disease and diabetes, other causes of mortality and morbidity are also affected such as cancer (Hou, et al., 2004) and depression (Ohta, Mizoue, Mishima, & Ikeda, 2007). The benefits to health are stronger and more consistent for cycling than for walking to work, because of the greater intensity of activity involved in cycling. The cohort studies also suggest that benefits become stronger with longer follow-up.

Although most studies have included only walking and cycling as active forms of transport in their assessments of physical activity in the trip to and from work, there is emerging evidence from cross-sectional studies that the physical activity associated with using public transport can also contribute to reaching healthy levels of regular exercise (Besser & Dannenberg, 2005; Edwards, 2008; Villanueva, Giles-Corti, & McCormack, 2008).

Prospective studies are useful for identifying the health benefits of existing levels of commuting-related physical activity but assessing the likely benefits of changing people’s commuting behaviour is more difficult. People who use active modes of transport are likely to be younger, fitter and otherwise healthier than those who do not, and controlling for these confounders in observational studies is incomplete. Those who change their behaviour from passive to active transport are likely to have similar characteristics. Furthermore, it is not clear whether increasing transport related walking and cycling results in a net increase in physical activity rather than a substitution for recreational physical activity. A recent systematic review of intervention studies to promote walking and cycling overall (Ogilvie, et al., 2007) identified a single promising randomised controlled trial (Mutrie, et al., 2002), which used a self-help intervention to successfully increase the amount of walking to work, with improvements in self related health (measured by the SF-36 questionnaire). However, the study did not measure other kinds
of physical activity undertaken by participants, nor report on the baseline characteristics of participants in each group.

Sport and Recreation New Zealand undertakes regular population surveys to estimate levels of physical activity in the population, as well as the types of physical activity undertaken. From the 2007/2008 survey (Sport and Recreation New Zealand, 2008) 48.2% of New Zealanders met physical activity guidelines of at least 30 minutes of moderate intensity activity on most days of the week. About 13% were inactive. These results are consistent with rates of physical activity across developed countries (Dora & Phillips, 2000). Māori, Pacific and New Zealand Europeans surveyed were similarly active, while those surveyed of Asian ethnicities were significantly less likely to meet the guidelines (37.8%), and more likely to be inactive (21%). Of the people who did meet the guidelines 8% met them solely through transport-related physical activity and for a larger proportion of people active transport made some contribution to meeting the guidelines. Estimates suggest that over 96% of people can walk, and over 75% can ride a bicycle and these forms of activity are already among the most popular ways that New Zealanders are recreationally active (Sport and Recreation New Zealand, 2008). Active transport therefore has a much greater potential for assisting New Zealanders to be sufficiently active.

If the potential health benefits of increasing commuting physical activity are to be realised, transport policies will need to reflect the evidence about influences on transport-related walking and cycling. Interventions aimed at increasing physical activity have largely focused on behaviour change in leisure time physical activity, relying on cognitive influences on personal behaviour. Although the systematic review of interventions to increase walking previously alluded to concluded that individually tailored behavioural interventions offered some measure of success in increasing walking to work, the authors also acknowledged that studies attempting to intervene in the environmental influences on active transport were much more difficult to implement and evaluate (Ogilvie, et al., 2007). There is therefore a strong bias towards studies designed to test individual behavioural interventions.

There is some evidence that environmental factors may over-ride cognitive behavioural influences, particularly when aspects of the environment act as barriers to walking and cycling (Owen, Humpel, Leslie, Bauman, & Sallis, 2004). One study in Western Australia
(Giles-Corti & Donovan, 2003) found that individual, social and environmental factors had equal influence on whether people walked for transport. Environmental factors on their own have also been the subject of research, almost always relating to influences on walking and walkability. This research tends to emphasise the inseparable relationship between transport and land use policies. A systematic review published in 2008 (Saelens & Handy) identified 29 empirical studies published from 2005-2006, with consistent positive relations between walking for transportation and urban density, distance to a variety of destinations and land use mix. More recent studies continue to confirm this relationship (for example, McCormack, Giles-Corti, & Bulsara, 2008), including early evidence that enforced urban containment policies (such as a metropolitan urban limit) are associated with increased walking and cycling to work (Aytur, Rodriguez, Evenson, & Catellier, 2008).

Although most countries have seen significant declines in commuter cycling rates over the past decades (Pucher & Dijkstra, 2003), environmental influences on cycling have not been as well researched. Several studies have attempted to identify both barriers to cycling and transport policies from cities and countries that have been successful in increasing commuter cycling. Concern about safety from injury has consistently been identified as a major barrier to cycling in the US, Australia and New Zealand, all countries with low rates of cycling (Cleland & Walton, 2004; Garrard, Rose, & Lo, 2008; Goldsmith, 1992). Studies by Garrard and her colleagues (Garrard, Crawford, & Hakman, 2006; Garrard, et al., 2008) in Australia show that safety concerns are felt more strongly by women than by men, and this is likely to explain the gender differential in countries with low cycling rates.

It is clear from the evidence described above about the barriers to transport related walking and cycling, that successful policies to encourage active transport will overlap with those that reduce the real and perceived risk of injury to pedestrians and cyclists that have been described previously (see Section 2.2.1). Pucher and Dijkstra (2003) have synthesised the transport and land use planning policies that are likely to make the most difference in encouraging both walking and cycling for transport, and they suggest the following policies:

1. Infrastructure and facilities that make walking and cycling safer from injury
2. Traffic calming of residential neighbourhoods
3. Urban design oriented to people rather than cars
4. Restrictions on motor vehicle use
5. Driver training that includes avoiding collisions with pedestrians and cyclists
6. Traffic regulation and enforcement that favour pedestrians and cyclists

2.2.3. Mental wellbeing

The effects of commuting on mental wellbeing include the beneficial effect of regular physical activity on depression already mentioned above. Other negative effects on mental wellbeing relate to psychological stress. Emerging areas of research suggest that commuting time and congestion both have direct effects on stress. The physical health effects of road traffic noise on health are mediated by annoyance and stress via cardiovascular risk factors (Babisch, 2002), and traffic noise is increasingly recognised as a major public health issue (World Health Organization Regional Office for Europe, 2007). I have therefore included a review of noise relevant to commuting in this section. The impact of managing time budgets associated with commuting to work and competing family responsibilities are also increasingly recognised, and this is identified as a particularly gendered issue, with women continuing to carry a higher burden of this kind of stress. The links between commuting and stress are outlined in this section, drawing on epidemiology, health psychology, transport, and feminist geography and planning literatures.

Stress contributes significantly to the burden of disease from depression and other mental disorders (R. J. Turner, Wheaton, & Lloyd, 1995), health care expenditure (Lantz, House, Mero, & Williams, 2005) and work absenteeism (Goetzel, et al.). Although there are very few studies on the direct relationship between commuting and stress levels (psychological or physiological) in the general population, lessons can also be drawn from studies of extreme exposures and outcomes, in particular from studies of the aggressive and violent driving behaviour known as “road rage”.

Most of our understanding about the direct link between commuting and stress comes from cross-sectional studies published in the health psychology literature. In 1988, Costa, Pickup and Martino reviewed studies of commuting and stress, linking physiological measures such as heart rate, catecholamine excretion and blood pressure to complicated driving, crowded public transport trips and the length of the journey to work. Novaco and his colleagues (Novaco, Kliewer, & Broquet, 1991; Novaco, Stokols, & Milanesi, 1990;
Stokols & Novaco, 1981) investigated the impacts of commuting on both physical, objectively measured health related outcomes and subjective measures of satisfaction and mood in five studies in the US. Their convenience sampled cross-sectional and longitudinal studies used objective and subjective measures of “physical impedance” in the trip to work. However, the objective measure of impedance used in their earlier studies was simply a measure of speed in the trip to work, which may bear little relationship with congestion particularly for short trips (Novaco, et al., 1990). The studies which measured subjective impedance found an association with evening mood and chest pain, but not with other health and satisfaction measures (Novaco, et al., 1990), or effects on family life (Novaco, et al., 1991).

A more recent prospective cohort study in the Netherlands (Jansen, Kant, Kristensen, & Nijhuis, 2003) provides some evidence that long commute times (in this case 30-60 minutes) is an antecedent for work-family conflict, defined as a perceived shortage of energy or time to fulfil work and family roles (Grandey & Cropanzano, 1999). Differences between commute mode were not considered in this study. However, the duration of rail commutes has separately been found to be associated with objective and subjective measures of stress in a convenience sample of rail commuters in the US (Evans & Wener, 2006). Gottholmseder, Nowotny, Pruckner and Theurl (2009) explored further the links between different modes of commuting and perceived stress in a randomly selected cross-section of Austrian commuters, and found that rather than being dependent on commute mode itself, it was significantly associated with longer and less predictable commute time, as well as the perception of opportunity cost (i.e. that the time spent commuting was “lost” to other purposes), supporting the work of previous authors.

Another potential indicator of a more generalised problem of commuting-related stress is extremely aggressive or violent driver behaviour. Smart and Mann and their colleagues have undertaken preliminary research (Mann, et al., 2007; Smart & Mann, 2002; Smart, Mann, Zhao, & Stoduto, 2005; Smart, Stoduto, Mann, & Adlaf, 2004) investigating the phenomenon known popularly as “road rage”. They suggest a taxonomy of road rage that includes a range of behaviours from expressions of anger and frustration, physical intimidation, verbal threats, to causing injury and death to other drivers, passengers or other road users (Smart & Mann, 2002). They have undertaken the only prevalence studies of road rage, in Canada, which suggest about 30% of people perpetrate some kind of road rage over the period of a year (Smart, et al., 2005). Studies investigating
underlying factors associated with road rage have consistently found that road rage incidents occur most commonly during evening commute times (Asbridge, Smart, & Mann, 2006; Harding, Morgan, Indermaur, Ferrante, & Blagg, 1998; D. Parker, Lajunen, & Summala, 2002; Sarkar, Martineau, Emami, Khatib, & Wallace, 2000; Smart, et al., 2004) and in congested conditions (Hennessy & Wiesenthal, 1999). These studies support the theory that road rage is an extreme expression of stress related to driving congestion.

Road traffic noise has been calculated as second only to ambient air pollution in its contribution to the environmental burden of disease in Europe in the recent six countries pilot study (Jantunen, et al., 2011). There is increasing understanding about the effects of commuting road traffic noise on health via annoyance and stress, including that they are cumulative and mostly at levels below those that cause hearing damage. Although research has also focused on the effects of traffic noise on sleep disturbance these are harder to attribute to commuting, which usually occurs in daylight hours. During the day, traffic noise acts as a stressor through annoyance and this is thought to mediate the effects of noise on health (Moudon, 2009; Niemann & Maschke, 2004; Passchier-Vermeer & Passchier, 2000). Most of the studies of noise and health have been conducted in Europe, where traffic noise is the dominant source of environmental noise pollution (Niemann, et al., 2006). Evidence has mainly come from cross-sectional studies. These have found consistent but confounded associations between chronic road traffic noise exposure and cardiovascular disease in adults (Björk, et al., 2006; Bluhm, Berglind, Nordling, & Rosenlund, 2007; de Kluizenaar, Gansevoort, Miedema, & de Jong, 2007; Dratva, et al., 2010; Ising & Kruppa, 2004; Niemann & Maschke, 2004), as well as more recently an association with health-related quality of life (Dratva, et al., 2010). In an exception to the dominant cross-sectional study design, Babisch and his colleagues (Babisch, Beule, Schust, Kersten, & Ising, 2005; Babisch, Ising, Elwood, Sharp, & Bainton, 1993; Babisch, Ising, Gallacher, & Elwood, 1988; Babisch, et al., 1990; Babisch, Ising, Gallacher, Sweetnam, & Elwood, 1999) have undertaken both cohort and case-control analyses of road traffic noise and cardiovascular outcomes. In the Caerphilly and Speedwell heart disease studies (Babisch, et al., 1993; 1988; 1990; 1999) approximately 4500 men in England and Wales were followed up for 10 years and the incidence of myocardial infarction or death from ischaemic heart disease was measured. No significant association was found between any of the measures of noise exposure and the heart disease outcomes (Babisch, et al., 1999). The hospital-based case-control study (Babisch,
et al., 2005) investigated the link between myocardial infarction and chronic noise exposure, finding a clear dose-response effect for men but not for women, controlling for other cardiovascular disease risk factors.

Many studies use annoyance as a proxy for the stress and therefore health effects of noise exposure. Although research has found a close correlation between levels of road traffic noise and levels of annoyance, with sensitivity to small changes in noise levels (Dravitzki, 2006) little is known about the validity of annoyance as a predictor of stress levels and health outcomes.

A further major limitation of noise and health research in all population groups is the inability to separate noise harm from the effects of air pollution, as the two are so closely inter-related (World Health Organization Regional Office for Europe, 2007). Two studies from 2009 have attempted to separate these effects. A population case-control study from the United States (Selander, et al., 2009) found a very high correlation between noise and air pollution levels, but a dose-response relationship between noise levels and myocardial infarction remained after controlling for air pollution, with an odds ratio of 1.38 (95% CI 1.11–1.71) for road traffic noise ≥ 50dB as an average exposure over approximately 20 years. Beelan, et al. (2009) used the Netherlands Cohort Study of Diet and Cancer to analyse the effects of air pollution and noise on cardiovascular deaths. Using participant addresses and mapped noise levels, they found a significant association between ambient noise ≥ 65dB and total cardiovascular deaths which remained after controlling for air pollution variables.

The detrimental effects of commuting-related traffic noise on the health of specific vulnerable populations are also likely to be important. For instance, there is likely to be a greater effect of road traffic noise on children during school or preschool hours (Belojevic, Jakovljevic, Stojanov, Paunovic, & Ilic, 2008; C. Clark, et al., 2006; Stansfeld, et al., 2005), as well as on other vulnerable populations such as hospital patients, although these have been the subject of very little research.

Rail noise has also been identified as a problem in international studies of urban noise. A number of social surveys have explored the relationship between railway noise and annoyance, with findings in European indicating that railway noise is less annoying than road traffic noise for the same level of noise (Miedema & Vos, 1998), but that this is not the case in other countries such as Japan or Korea (Kaku & Yamada, 1996; Lim, Kim,
Hong, & Lee, 2006; Morihara, Sato, & Yano, 2004; Yano, Yamashita, & Izumi, 1997). These differences may be attributable to train types, housing quality and density, or cultural factors (Lim, et al., 2006; Sato, Yano, Björkman, & Rylander, 2002).

Despite the lack of convincing epidemiological evidence linking road traffic noise and either stress or health outcomes, the WHO Regional Office for Europe have recently quantified the burden of healthy life years lost in western Europe due to environmental noise (Fritschi, Brown, Kim, Schwela, & Kephalopoulos, 2011). Excluding sleep disturbance, this was calculated to be in the order of 100,000 years lost, most of which was due to road traffic noise.

There are no useful epidemiological data from New Zealand to assess exposure to the levels of road traffic noise found to be harmful in the studies described above. It is difficult to extrapolate from the European burden of disease study described above. The only data come from a single unpublished survey of a thousand Auckland residents (Lyne & Moore, 2004) which found that 82% of residents in high-density dwellings and 69% in stand-alone dwellings were bothered by noise, most of which was attributed to traffic.

The opportunity cost of the time spent commuting and people’s ability to manage their family responsibilities is a further cause of stress in the journey to work described in the literature. People with care obligations, either of dependent children or elderly relatives, still tend to be women, and this is likely to be an important influence on women’s commuting patterns (Ortoleva & Brenman, 2004; Schwanen, 2011; Strazdins & Loughrey, 2008; Timmermans, et al., 2002). The stress effect of managing time budgets within spatial constraints has long been recognised in feminist discourse as a gendered issue epitomising the interconnectedness of land use and transport (Hayden, 1980; Huxley, 1988; Madden, 1977; Young, 1980). This is discussed further below.

A number of researchers in the UK have focused on the time constraints of women combining employment with family responsibilities in their daily lives (Dobbs, 2005; Pickup, 1984; Rosenbloom & Burns, 1994). They demonstrate that the phenomenon of “trip-chaining” (having a number of intermediate stops in a journey) is dominant in women’s trip to work, making it difficult to use any other mode of transport than the private car for this purpose. In particular the location of childcare was an important influence in how women managed their time, influencing the trip to work (Dobbs, 2005). Others have attempted to enrich this discourse of car reliance with cultural perspectives.
Schwanen’s survey of households in Utrecht (2011) found that women’s car use was strongly associated with social expectations of being a “good” parent (providing children with sufficient care) in tension with anxieties about being an adequate employee. This association of good parenting with driving children to school and other activities was also a dominant theme in qualitative work by Dowling with Sydney mothers (2000) and Bean, Kearns and Collins in Auckland (2008). The suburban mothers in Sydney emphasised the connection between car use and the provision of what was best for their children. In the Auckland study, parents described how commuting by car allowed them to spend time talking to their children while driving or after work, because they had been able to return home faster than would be possible by other modes. However, Schwanen (2011) also found that the notion of good parenting could be expressed through other modes of transport, particularly cycling (for example teaching children how to ride safely and imbuing environmental awareness). Similarly, in the Auckland study, Bean and her colleagues found an emerging connection between walking children to school and good parenting, partly by meeting social expectations, but also by connecting socially as a family with other neighbourhood families.

Much of the research about time use and the trip to work has considered commute time as time lost to other activities or opportunities (Costa, et al., 1988; Mokhtarian & Chen, 2004); however there is some evidence that time spent commuting is not always considered wasted. For instance, the evidence about active modes and physical activity described in Section 2.2.2 suggests that active transport can provide a “double dividend” in the form of time saved on physical activity undertaken for fitness during leisure time. In addition, there is a small amount of qualitative research suggesting people use the commute time on trains for leisure activities, stress relief and social connection (Letherby & Reynolds, 2003). The particular importance of walking for opportunistic connection within neighbourhoods, and therefore the development of a sense of community and social trust has also been identified (Leyden, 2003; Lund, 2003), suggesting that walking to work is likely also to be important for mental wellbeing through social connection.

2.2.4. Local environmental wellbeing

This includes the inner “physical environment” circle of Hancock’s ecosystem health model, and both mauriora (connection to culture) and waiora (environmental wellbeing) in Durie’s Te Pae Mahutonga. The impact of commuting itself on local ecosystems is
difficult to quantify. However, the increasing demand for commuter travel, and the consequent congestion at peak travel times, has a significant influence on the provision of new transport infrastructure, and in car-dominated cities this leads to the building of more roads. We can therefore draw inferences about the effects of commuting by considering the effects of increased road building on the ability of cities to fulfil ecosystem services (benefits of ecosystems to human populations), and can consider as a conservative underestimate the *pro rata* contribution of commuting to these effects. For instance, commuting currently contributes about a quarter of all trips in Auckland (L. Povey, personal communication, January 10, 2012); therefore the contribution of commuting to these effects could be expected to be at least 25%.

Bolund and Hunhammer (1999) have defined important urban ecosystems that provide benefits to human populations in cities, and also described the benefits they provide. These are summarised in Box 2. Expansion of motor vehicle based commuting affects all these urban ecosystems. Reviews synthesising the effects of roads on ecology cover the effects of both rural and urban roads, which have very different contexts in terms of the existing quality of local ecosystems and the intensity of effects. In urban environments, mechanisms such as environmental impact assessment can estimate the ecological effects of adding a single new road, but considering the effects of the existing network is more difficult. The field of road ecology (Forman & Alexander, 1998) is a recent one, emerging from landscape ecology and biological conservation (Coffin, 2007). A number of recent reviews are helpful in understanding the ecological effects of roads (Coffin, 2007; Forman, et al., 2003a; Pickett, et al., 2001; Spellerberg, 1998), and in summarising these I have developed aspects of particular relevance to urban road networks.
Chapter 2 - Background

Box 2 Urban ecosystems and their benefits (Bolund & Hunhammer, 1999)

<table>
<thead>
<tr>
<th>URBAN ECOSYSTEMS</th>
<th>BENEFITS</th>
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<tr>
<td>Cultivated land</td>
<td>Micro-climate regulation</td>
</tr>
<tr>
<td>Street trees</td>
<td>Air filtration</td>
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<tr>
<td>Lawns and parks</td>
<td>Storm water/sewage drainage and filtration</td>
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<tr>
<td>Urban forests</td>
<td>Food production</td>
</tr>
<tr>
<td>Wetlands</td>
<td>Cultural, spiritual and recreational value</td>
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<tr>
<td>Streams</td>
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<td>Lakes and sea</td>
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Road building has a land use opportunity cost within metropolitan urban limits, and most often this cost is a loss of green space. As car dependence and population growth lead to sprawl, this cost extends to peri-urban productive land and wilderness (Pickett, et al., 2001). Roads are not only ecological vacuums themselves, but they also sever and shrink remaining green areas into fragments, limiting the ability of those fragments to support biodiversity (Fahrig, 2003) and provide ecosystem services such as mitigating urban heat island effects (Pickett, et al., 2001). Roads are also a barrier to the movement of wildlife, and motor vehicles are a direct cause of mortality to birds and animals as “road kill” (Coffin, 2007). Road corridors also have a direct effect on micro-climate, as these corridors are windier, sunnier, hotter and drier (Forman, et al., 2003b).

The water-impervious nature of roads contributes significantly to overall impervious surface coverage in cities which increases the risk of flooding. High volumes of unfiltered storm water also run off into vulnerable coastal and fresh receiving waters. The detrimental effects of this run-off are compounded by the wide range of suspended and dissolved pollutants from motor vehicles, including rubber, oils and heavy metals (Spellerberg, 1998). This polluted run-off has negative effects on aquatic ecosystems as well as direct human health impacts from recreational exposure to polluted streams, lakes and coastal water (Spellerberg, 1998; Trombulak & Frissell, 2000).
Much more devastating consequences for freshwater ecosystems occur when urban waterways are re-directed to make way for roads, diverting entire freshwater ecosystems into subterranean concrete drainage pipes (Coffin, 2007; Trombulak & Frissell, 2000).

Heavy metals in road dust accumulate in plant life near roadsides, influencing the growth of the plants themselves, bio-accumulating in birds and animals, and also harming human health if these plants are then used for food (Forman & Alexander, 1998). The density of roads and traffic in urban areas makes the contamination of soil and plants likely to be both ubiquitous and insidious. The health implications of fruit and vegetable contamination with heavy metals may hamper efforts to increase urban food production to meet environmental sustainability and nutrition objectives (Smit & Nasr, 1992).

As well as their effects on human health, the air pollution and noise effects of road traffic discussed above also have impacts on ecosystems. For example there is emerging evidence about the effects of noise on bird behaviour (Slabbekoorn & Peet, 2003), as well as the effects of air pollutants on plant growth and photosynthesis (Farmer, 1993).

There has been recent interest in the opportunities that both roads and railways offer as “biodiversity corridors”, with conflicting conclusions. In some instances urban roads may act as a conduit for the movement of native species from one habitat to another, when verges are well-designed, but more often it is invasive species of plants, animals and insects whose movement and dispersal is facilitated by roadways (Coffin, 2007).

The “biophilia hypothesis” of E.O. Wilson (1993) proposed the importance of contact with biodiversity to human health, and led to a growing area of research about this link (St Leger, 2003). Research to date suggests that exposure to nature in daily life (Leather, Pyrgas, Beale, & Lawrence, 1998; Maller, Townsend, Pryor, Brown, & St Leger, 2006), opportunities to garden, and contact with animals and birds have all been found to be associated with improved psychological wellbeing (Maller, et al., 2006). In New Zealand, there has been significant rural-urban migration since the 1950s, and this has been most rapid and pronounced for Māori (Barcham, 2004; R. Walker, 1990). The resultant disconnection from traditional lands and native biodiversity has contributed to a loss of cultural wellbeing, or mauriora (Panelli & Tipa, 2007). The ability to have contact with native biodiversity and cultural landscapes in urban settings therefore has the potential to be important for urban cultural wellbeing generally, but particularly for migrated Māori communities. There is an even stronger link between the quality of urban native and
cultural landscapes and the wellbeing of Tangata Whenua (the particular iwi or tribe who have ancestral guardianship, or kaitiakitanga) of urban areas (Hoskins, 2008).

In addition to the impacts of road building on the amount and quality of green space within cities, the dominant pattern of commuting by car which drives new road building also therefore reduces the opportunity for wellbeing enhancing contact with nature, in particular native biodiversity.

Urban trips to work not only make pro rata contributions to the local ecosystems where they are undertaken, but are also a significant assumed foundation of the economic growth that continues to impel oil exploration and extraction with wider implications for global ecosystems. Taking a “well to wheels” approach (Fiksel, 2006) to the impact of commuting requires us also to consider the effects of oil exploration, transport and refinement. In the context of diminishing oil supplies, each new barrel of oil is extracted at increasing financial, human and environmental cost (Bentley, 2002; Borasin, et al., 2002; Hubbert, 1949; Sorrell, Speirs, Bentley, Brandt, & Miller, 2010). New oil extraction is turning to processes such as very deep ocean drilling, and the extraction of very heavy oil from tar sands and shale, as well as to countries characterised by political instability and lax environmental and health regulations (Borasin, et al., 2002; O'Rourke & Connolly, 2003). As has been seen recently with the Gulf of Mexico oil spill, and the ecological consequences of Alberta’s tar sands industry, these extraction processes can have very high costs to terrestrial and marine environments (Borasin, et al., 2002). Furthermore, the greenhouse gas emissions associated with the extraction and refinement of heavy oil from tar sands is up to four times that emitted in the conventional production of refined oil (Charpentier, Bergerson, & MacLean, 2009).

2.2.5. Participation in society

The design of urban transport systems is foundational to people’s fair participation in the labour market while also being able to participate in their families and wider society (Lucas, 2011). This section therefore includes the way that access to work links the physical urban environment and the socioeconomic aspects of the ecosystem health framework, and supports Durie’s notion of te oranga (participation in society and access to services). It focuses particularly on exclusion from employment due to transport barriers.
Transport policy is the main influence on the way the urban built environment is designed, and the converse is also true (Frank, Kavage, & Litman, 2006; Frumkin, 2003; Frumkin, Frank, & Jackson, 2004). Car dominant transport systems have led to sprawling patterns of urban development, and along with zoning regulations have also influenced land use patterns (Frumkin, et al., 2004). “Sprawl” has been defined as a combination of low density development, poor street connections, and separated land use (Gillham, 2002). There is a cyclical nature to the relationship between car use and sprawl, in that increasing car use has led to sprawling land use patterns, which then leads to further car dependence (Frumkin, 2003). Of particular relevance to commuting patterns, the separated land use associated with sprawl has increased the distance between housing and workplaces. This influences car dependent commuting and creates circumstances conducive to social exclusion in labour market participation by deprivation, gender, ethnicity and disability (Clifton & Lucas, 2004). Social exclusion is considered to describe barriers that make it difficult for people to “participate fully in society or obtain a decent standard of living” (Stanley & Vella-Brodrick, 2009), and is an important mediator of wellbeing (Currie, et al., 2009; Stanley & Stanley, 2007).

As far back as 1944, Liepmann (a British sociologist) identified the problem of “severance” of dwellings and workplaces and the implications for transport, citizenship and community wellbeing. In her seminal book The Journey to Work (Liepmann, 1944) she concluded that “the burden of the daily journey overshadows the essential services which it renders” (p. 191). She also identified that the costs of the trip to work were borne by the worker, and by society (in the provision of subsidised transport), while these trips were contributing to the profits of the employers. Although Liepmann saw the rapid growth in private car ownership in the US during this time as a way forward for improving the efficiency of commuting, she stressed that this could only be positive under the circumstances of car pooling (with 2-3 workers per car) and shared vehicle ownership. She also concluded that a much more important intervention was in town planning – the location of a variety of “alternative workplaces within daily reach of every earner” (p. 194).

This identification of the unequal cost of commuting was later echoed by the radical socialist thinker Ivan Illich in Energy and Equity (1974). Illich concluded that once the social and time costs of car use were accounted for, the “social speed” or “effective speed” of the bicycle could be greater, and more equitable, than the car. Examining the
total financial, social and time costs of different modes to households and society can provide an indication of the level of social exclusion caused by car dependence, as well as the opportunity costs of car dependence on other aspects of social welfare (Lucas, 2004).

However, in car dominated cities car ownership becomes a prerequisite for access to employment, along with access to other goods and services. Indeed, in many developed countries lack of access to a car is used as a proxy for social exclusion or socioeconomic deprivation, including in the US, UK, and New Zealand (Krieger, Williams, & Moss, 2003; Salmond, Crampton, & Atkinson, 2007). A review of transport mediated social exclusion in the UK concluded that two out of five people looking for a job stated transport was a barrier to employment, and a quarter of young people also identified lack of transport as a reason for not applying for a job (Social Exclusion Unit, 2003). Other UK evidence suggests that while car ownership has become more universal despite socioeconomic deprivation, the poorest car owning households may be making financial sacrifices in order to purchase, maintain and operate their cars (Clifton & Lucas, 2004). This kind of car ownership has been described as “forced car ownership” in Australia, to emphasise the lack of choice for low income families in adverse urban contexts (Currie, et al., 2009). Australian research has also explored the characteristics of public transport users, and conversely identified a kind of bus “captivity” in Melbourne, with more than 70% of weekday riders not having access to a car and almost half having very low incomes (Loader & Stanley, 2009).

In New Zealand a single national survey undertaken in 1997 (and not repeated since) by the Department of Labour examined barriers to employment for longer term jobseekers (B. Parker, 1997). The survey identified lack of access to private or public transport and lack of a driver’s license as by far the greatest barriers. Our own work (Macmillan, Kang, & Lindsay, 2009) has demonstrated that the proportion of household income spent on car ownership, maintenance and operating costs increases with increasing deprivation. Figure 2-5 demonstrates the gradient of household expenditure on motor vehicle fuels in 2008 by deprivation decile (NZDep2006 (Salmond, et al., 2007)). The gradient indicates that households are unable to curtail trips or change the mode of their trips to reduce this proportion. Despite public transport being considered unreliable and of poor quality in most New Zealand cities, a survey similar to the one described in Melbourne found that three quarters of the public transport passengers had no other alternative for the surveyed trip (Booz Allen Hamilton, 1998).
The Auckland Regional Public Health Service has mapped access to public transport by level of socioeconomic deprivation in the Auckland region (Submission from the Auckland Regional Public Health Service on the "Annual Plan 2008-2009 and amendments to the LTCCP" 2008). Their work demonstrates that the likelihood of living within 1km of a railway station decreases with increasing deprivation (decreasing the ability of the poorest communities to take advantage of the rapid transit network), whereas the likelihood of living within 1km of a railway line increases with increasing deprivation (increasing exposure to noise, air pollution and risk of injury). Transport modelling undertaken by Auckland Regional Council also identified inequities in access to all forms of public transport by neighbourhood socioeconomic deprivation (Auckland Regional Transport Committee, 2007). In 2006 approximately 75% of people in areas with high deprivation (NZDep2001 levels 9 and 10) had “low” or “average” levels of access to public transport services. These double inequities highlight public transport access as an environmental justice issue for the region.

The mismatch between transport access, urban design and the needs of women identified in the 1970s and 1980s by feminist planners has been outlined previously (Section 2.2.3). The gendered division in transport that facilitates women’s physical and social exclusion, and creates unequal positions in the labour market, continues to be relevant (Dobbs, 2007; Ortoleva & Brenman, 2004). Qualitative research with women across social strata in the
UK (Dobbs, 2007) has identified shifting constraints upon women’s travel behaviour and access to employment over the life course. In particular, gendered divisions of transport access and childcare responsibilities within families, real and perceived safety in neighbourhoods and on public transport, geographic separation from workplaces and a mismatch between public transport services and part-time work hours were identified as barriers to equal participation in employment for women. However, Hanson (2010) argues that much of this research has simplistically conflated mobility (for instance distances travelled) and access to a car with access to employment, and objective measures of employment with balanced choices. She argues for a more nuanced understanding of the ways that women balance career goals with other values of caring (such as caring for children, the community or environment) when they choose where to work and how they get there.

The identification of inequities in access to transport in the US has also focused on legal aspects of racial discrimination under Civil Rights Law (Cervero, 2004). African Americans and Hispanic populations are over-represented in poor neighbourhoods in the urban centres, while employment centres are found in suburban clusters (Lang, 2003). These spatial factors are combined with marked inequalities in car ownership by ethnicity, with four times the rate of “car-lessness” among African American households than white households in 2001 (Clifton & Lucas, 2004), making commuting by public transport more common (Chung, Myers Jr, & Saunders, 2001). In addition, provision of public transport from these inner city communities to suburban employment centres has been sufficiently poor to spark civil unrest (Cervero & Tsai, 2003). Evidence of racial profiling on the part of police officers in the US has become more convincing over the past decade (Kowalski & Lundman), and has led to the coining of terms such as “driving while black” (Lundman & Kaufman, 2003; Meeks, 2000) and “driving while brown” (Ortoleva & Brenman, 2004).

The previously mentioned Department of Labour survey of long term job seekers (B. Parker, 1997) in New Zealand found that transportation to work was a greater issue for Māori and Pacific job seekers. The over-representation of Māori and Pacific households in neighbourhoods of high socioeconomic deprivation (Ministry of Health & University of Otago, 2006), combined with the regional public transport findings described previously, means these households are also likely to experience inequalities in public transport provision, although this has not been studied. The complex links between
ethnicity, poverty, illegal driving and racial profiling seen in the US are also highly likely to be present in New Zealand and contribute to exclusion from employment and wider participation in society, particularly for Māori and Pacific men. Although these links have rarely been specifically studied, significant associations have been shown between Māori and Pacific ethnicity and driving unlicensed or with a disqualified license (Blows, et al., 2005), while convictions for traffic offences are four times higher for Māori and twice as high for Pacific than for European New Zealanders (Hook, 2009).

People with disabilities are also more likely to be reliant on public transport, be over-represented in neighbourhoods of high socio-economic deprivation and experience poor access to higher education and employment that is a function of access not ability (J. Jensen, et al., 2005; Organisation for Economic Co-operation and Development [OECD], 2003; Wilkins, 2003). Although people with disabilities are consistently identified as “transport disadvantaged” in research about social exclusion and transport as well as in transport policy documents, little transport social exclusion research has focused specifically on this group. Policy recommendations aimed at improving equity of secure employment for people with disabilities have largely ignored transport disadvantage as a potential barrier (Jansen, et al., 2003; OECD, 2003).

Policy recommendations to improve social inclusion through transport policy are reasonably consistent. Provision of improved affordable public transport services to meet the needs of the groups described above can improve access to employment, education and other goods and services. Implementing this recommendation has to date involved the provision of “special” public transport services to particular communities (Battellino, 2009; Cervero, 2004; M. Jones, 2004; Lucas, Tyler, & Christodoulou, 2009). These community level projects undergo specific evaluation, and because they are separated from mainstream public transport services their funding in the long term remains vulnerable. Both Melbourne and Bogota have taken a different approach, improving the accessibility, affordability and coverage of overall public transport services, and prioritising service improvements to geographical areas characterised by deprivation (Loader & Stanley, 2009; Sandoval & Hidalgo, 2002). These interventions have been successful in increasing bus patronage, thereby making mainstream bus services more inclusive as well as more financially viable. In addition, urban planning that provides for a mix of housing types combined with a variety of local employment opportunities, improves neighbourhood walkability, and safe opportunities for cycling has been
recommended (Currie, et al., 2009). Changes to the transport policy-making process to improve the participation of a wide range of stakeholders in decision-making have also been recommended to assist with the development of a more inclusive transport system (Hodgson & Turner, 2003).

2.2.6. Biosphere

The effects of urban transport systems on global ecological systems mainly occur through their heavy reliance on fossil fuels, and contribution to climate change. Warming of the global climate is unequivocal, and there is near universal consensus among climate scientists that the world has begun to warm as a result of increasing anthropogenic greenhouse gas emissions (mainly carbon dioxide and methane) (Intergovernmental Panel on Climate Change, 2007). Furthermore, it is becoming less likely that international co-operative action will be sufficient to limit this warming to the 2°C argued that may minimise climate change impacts on ecosystems and therefore society (Meinshausen, et al., 2009; Moss, et al., 2010). This means that adaptation to climate change will be as important as reducing greenhouse gas emissions (M. L. Parry, Lowe, & Hanson, 2009). It is also becoming clearer that climate change poses many risks to health and equity. Climate change has been described by the Lancet as “the biggest global threat to health of the 21st century” (Costello, Abbas, Allen, & et al, 2009). Although we can say with high levels of certainty that climate change is happening as a result of human activities, the impacts on wellbeing are more difficult to predict because there are different paths society can take in response to climate change, and because social and natural systems will respond unpredictably to tipping points.

International reviews have explored the effects of climate change on global health, including the direct and indirect effects of changes to the climate, as well as effects of policies to reduce greenhouse gas emissions (Confalonieri, et al., 2007; Costello, et al., 2009; McMichael, Woodruff, & Hales, 2006). These have culminated in the WHO’s recent report: Protecting health from climate change (2009b). Although there may be some short-term health benefits of climate change (such as reduced mortality from extremely cold weather), the threats to health overwhelm these benefits. Furthermore, the burden of risks to human health will be carried unequally by the poorest countries, and the poorest communities within countries, increasing health inequities (Patz, Gibbs, Foley, Rogers, & Smith, 2007; WHO, 2009b). McMichael, et al.(2006) provide a useful
diagrammatic summary of these main pathways for climate change effects on human health, and this is reproduced in Figure 2-6.

In New Zealand the health and equity effects of climate change have also been the subject of a number of reviews (Hales & Woodward, 2006; Howden-Chapman, Chapman, Hales, Britton, & Wilson, 2010; Macmillan & Hosking, 2010; Woodward, Hales, & de Wet, 2001). Flooding and erosion will be an increasing threat to settlements on the west coast of New Zealand, as well as Northland and the East Cape. Māori land and coastal settlements and economies are particularly vulnerable (Packman, Ponter, & Tutu-Nathan, 2001). Flooding and rising sea levels also threaten the supply of fresh water to coastal settlements (Costello, et al., 2009). A warmer climate is likely to create more
favourable conditions for food-borne illness (Howden-Chapman, et al., 2010), as well as the mosquitoes that carry dengue fever (Hales, de Wet, Maindonald, & Woodward, 2002; Hales & Woodward, 2006). Displacement of Pacific peoples because of climate change is likely to result in chain migrations to New Zealand, and consequent pressures on New Zealand’s Pacific communities already suffering from health and socioeconomic inequalities (Howden-Chapman, et al., 2010; Mimura, et al., 2007).

The contribution of road transport to the greenhouse gases responsible for climate change is well documented, being counted by countries in their required reporting under the Kyoto agreement (United Nations, 1998). Road transport accounted for about 17% of global carbon dioxide emissions in 2002, and private motor vehicles and road freight both dominated this sector (Chapman, 2007). Transport is also a rapidly growing sector in terms of emissions (Chapman, 2007). In New Zealand the contribution of road transport was similar to the global contribution (17.3%) and the fastest growing emissions sector, with an overall increase of 63% from 1990 levels (Ministry for the Environment, 2011). Commuting trips are relatively short and undertaken under congested conditions, and therefore produce more emissions per km travelled than a pro rata calculation would suggest (Chapman, 2007). These trips have therefore been targeted in climate change mitigation policies (Chapman, 2007).

Fortuitously, the transport policies that have been identified as likely to be most effective in reducing land transport’s contribution to climate change and reducing our reliance on new sources of oil, align well with policies described above to reduce other health effects of current commuting patterns (Haines, et al., 2007; Higgins & Higgins, 2005; Roberts, 2009; Woodcock, Banister, Edwards, Prentice, & Roberts, 2007). These include transforming urban transport systems to be public transport rather than private motor car dominated, increasing active transport in short urban trips and improving the technological fuel efficiency of the vehicle fleet (which would also reduce air pollution). However a number of other technical advances have the potential to worsen health or increase inequalities. For instance there is growing demand for biofuels as an alternative to petroleum for fuelling motor vehicles. However, emerging evidence suggests that crop-based biofuels compete with food crops for land, increasing the price of basic foods (Hill, Nelson, Tilman, Polasky, & Tiffany, 2006), and have greater aggregate environmental costs (Scharlemann & Laurance, 2008). Road pricing and fuel taxes are another policy option for reducing transport greenhouse gas emissions, however these taxes have the
potential to be regressive – their economic burden falling unfairly on the poorest households, reducing the ability of these households to meet their health and wellbeing needs (Dhar, Macmillan, Lindsay, & Woodward, 2009).

**2.3. Summary**

This review has described the very wide-ranging connections between the journey to work and human wellbeing using an ecosystem health framework. Rather than undertaking an exhaustive review of studies linking commuting and health I have illustrated the full range of relationships between commuting and public health across disciplinary literatures, emerging from a range of theoretical paradigms including epidemiology, sociology, feminism and ecology. Because Auckland is the setting for the thesis, I have reviewed the literature in the context of the kind of car-dominance that characterises many developed cities. Where possible I have also identified and discussed data and research specific to New Zealand and Auckland.

The links between commuting and health are complex and relate to all aspects of wellbeing identified in the two frameworks that underpin the thesis (Hancock’s ecosystem health model and Te Pae Mahutonga). The complexity makes unforeseen negative consequences and tensions between policy objectives very likely. There is therefore a need for planning tools or methods that can integrate the full range of outcomes, making trade-offs more explicit. Although many of the connections between commuting and public health are not specific to the trip to work (rather commuting’s contribution to wider transport effects on health), commuting also has special effects on public health by enabling labour force participation.

The review suggests that technological advances to address negative health and environmental impacts are often outstripped by growth in demand for car-dominated travel (Organisation for Economic Co-operation and Development, 1996), and that therefore a shift away from car dominated commuting patterns is needed. Policy recommendations demonstrate that aligning these agendas is possible, and necessary for avoiding unexpected negative consequences. To align health, sustainability and equity, the review suggests that these goals need to be integrated in transport planning. Furthermore, the review suggests that to ensure the access and wellbeing benefits of urban transport are more fairly distributed, transport planning needs to involve women,
people from a range of ethnicities (including indigenous people) and the socioeconomically disadvantaged.

In the next chapter I consider the extent to which connections between commuting and public health have been considered in transport policy in New Zealand and Auckland to date, in the light of international advances in sustainable transport planning. I also consider the effectiveness of current approaches to changing commuting behaviour in New Zealand
Chapter 3. New Zealand transport planning is unlikely to achieve healthy commuting

Using an ecosystem framework, I have identified that transport policies have a significant influence on a broad range of commuting and public health outcomes. In this chapter I consider how these outcomes are currently incorporated into New Zealand transport planning. I identify two diverging transport policy trajectories, and briefly describe the path that New Zealand has taken historically. I also describe a framework for sustainable transport that has emerged as a response to growing environmental and health concerns and analyse recent New Zealand transport policies using this framework. Although the inter-dependencies between land use and transport policy are acknowledged in this chapter, the focus is on transport policies, reflecting a persistent separation between land use and transport planning in New Zealand. The analysis of transport policies includes recent national legislation and strategies, as well as Auckland-specific transport strategies.

The policy analysis identified a heavy reliance on travel demand management and “soft” policies such as organisational travel plans to change commuting patterns in New Zealand by changing people’s behaviour. I have therefore described these concepts further. Workplace travel plans in particular have become a major focus for changing commuting behaviours. I have therefore considered these as a case study policy and report a systematic review of the effectiveness of workplace travel plans for reducing car use and improving public health to illustrate the likely effectiveness of behaviour-change focused approaches such as these.

3.1. Evolution of Transport policy making internationally

In the European and English-speaking countries of the world towards which New Zealand has traditionally looked for urban planning inspiration there have broadly speaking been two divergent transport policy directions (Harris, 2007; Lay, 2005; Low & Astle, 2009). In continental Europe urban planning has generally been strongly regulated to create densities and land uses that support public transport oriented transport systems and create active-transport friendly city centres (Hull, 2008). On the other hand transport policy and urban planning in the UK, US, Australia and New Zealand have followed a more de-
regulated path, with private urban land ownership and urban design leading to a sprawling car-dependent pattern of growth (Schiller, Bruun, & Kenworthy, 2010). These two directions have been described as “path dependencies” (Harris, 2007; Low & Astle, 2009), in other words, the initiation and self-perpetuation of a dominant set of positive feedback loops (Sterman, 2000, pp. 349-353). On the one hand, the strong regulation of land use has led to investment in public transport services which are economically viable because of the land use regulation, and which encourage further mixed use development along public transport corridors. On the other hand, sprawling urban design with separated land use and low connectivity creates a level of car dependency that requires further transport and urban planning policies to be car-centred. New Zealand’s de-regulated path dependency has resulted in one of the highest per capita vehicle ownership levels in the world (approximately 700 vehicles per 1,000 people) (Ministry of Transport, 2009b).

Over the last half century transport planning in high income countries has developed into a well-organised, rational and technocratic process, using spatial and engineering models that aim to predict future demand for mobility through population and travel changes over time, and then supply transport solutions to meet the predicted demand (Banister, 2002b; Lay, 2005). In the 1980s and 1990s road traffic crashes, congestion and air pollution began to attract more attention in transport planning. However, the cost-benefit analysis tools used for assessing transport projects were poorly equipped to consider these environmental and health side effects, particularly if they could not be quantified or monetised (Banister, 2002a; Willis, 2005). Accordingly, technical and engineering solutions were developed to respond to the acknowledged impacts, including removing the lead from petrol, improving safety features of both vehicles and roads, and reducing exhaust emissions.

The concept of environmentally sustainable transport emerged in the 1990s, particularly in the OECD\textsuperscript{7}, where it was recognised that motorised transport activity threatened the ability of countries to move towards sustainable development. The technological and engineering solutions to environmental and health impacts were being overwhelmed by growth in vehicle ownership and vehicle kilometres travelled per person (OECD, 1996), and the traditional “predict and provide” engineering approach to travel demand was

\textsuperscript{7} Organisation for Economic Co-operation and Development
Chapter 3 – Policy Analysis

acknowledged to be failing (Hull, 2008). The global impacts of transport systems on climate change were also recognised, and this was an important feature of discussions about sustainable transport. The OECD meetings and conferences in the 1990s resulted in a definition of sustainable transport that included public health:

“Transportation that does not endanger public health or ecosystems and meets mobility needs consistent with (a) use of renewable resources at below their rates of regeneration and (b) use of non-renewable resources at below the rates of development of renewable substitutes.” (OECD, 1996, p. 12)

In 2001 the European Union Council of Transport Ministers adopted a more comprehensive definition, including not just environmental and health sustainability but also economic and social aspects. According to the Ministers, a sustainable transport system:

- Allows the basic access and development needs of individuals, companies and societies to be met safely and in a manner consistent with human and ecosystem health, and promises equity within and between successive generations
- Is affordable, operates fairly and efficiently, offers choice of transport mode, and supports a competitive economy, as well as balanced regional development
- Limits emissions and waste within the planet’s ability to absorb them, uses renewable resources at or below their rates of generation, and, uses non-renewable resources at or below the rates of development of renewable substitutes while minimizing the impact on land and the generation of noise. (Rahman & van Grol, 2005)

The Ministers’ report strongly recommended a shift in transport planning approaches to what was called “integrated transport planning”. This has a contested definition (see for example May, Kelly, & Shepherd, 2005; Santos, Behrendt, & Teytelboym, 2010; Stead, 2008, 2010) and can refer to integration between transport outcomes (e.g. social, economic, environmental); between assessment approaches (e.g. health and environmental impact assessment); across and within organisations (e.g. land use and transport planners, central and local governance); and between land use and transport
planning (Hickman, Seaborn, Headicar, & Banister, 2010; Stead, 2010). The Ministers’ report describes integrated transport planning as having a central purpose of securing access to the goods and services people need in their daily lives, as opposed to meeting predicted demand for mobility. Furthermore, integrated transport planning includes full-cost accounting of options, incorporating the economic, social, health and environmental benefits and costs. A set of nine proposed principles for sustainable transport were developed that reflected these definitions of integrated transport planning and sustainable transport. The nine principles are summarised in Table 3-1.

<table>
<thead>
<tr>
<th><strong>Principle</strong></th>
<th><strong>Description</strong></th>
</tr>
</thead>
</table>
| Access                               | Entitlement to access  
Other people, places, goods and services  
Access to empowering information for behaviour change |
| Equity                               | Inter- and intra-generational equity  
Meeting the basic transport-related needs of women, the poor, rural people, people with disabilities  
Assisting developing countries to foster sustainable transport systems |
| Individual and community responsibility | Both individuals and communities have a responsibility to act as stewards of the natural environment |
| Health and safety                    | Protection of physical, mental and social wellbeing  
Protection of safety  
Enhancement of community quality of life |
| Education and public participation   | Community engagement in decision-making  
Empowering processes  
Adequate and appropriate information and resources to support participation |
| Integrated planning                  | Responsibility to pursue more integrated approaches |
| Land and resource use                | Efficient use of land and other natural resources  
Preservation of vital habitats for maintaining biodiversity |
| Pollution prevention                 | Meeting transport needs without generating emissions that threaten public health, global climate, biological diversity or the integrity of essential ecological processes |
| Economic wellbeing                  | Taxation and economic policies to achieve sustainable transport  
Economic wellbeing tied to sustainable development and community wellbeing  
Full cost accounting including future social, economic and environmental costs  
User pays full costs of mode |

Table 3-1 Draft sustainable transport planning principles (adapted from OECD Vancouver Conference proceedings (Organisation for Economic Co-operation and Development, 1996))
Although members from nine OECD countries undertook work to identify and incorporate policies towards environmentally sustainable transport as part of the OECD project (OECD Working Group on Transport, 2002), the degree of incorporation of these principles into national and regional transport policies has not been reported. In an exception, an assessment of organisational issues with enacting the principles has been described for five local authorities in England (Hull, 2008). The English experience highlights the need for partnerships across sectors which have shared legislative responsibilities (including national transport, local government and the health sector) for the successful implementation of these principles.

In addition to the principles outlined in Table 3-1, later work by the OECD transport working group (OECD Working Group on Transport, 2002) has identified groups of policies and a policy process for achieving environmentally sustainable transport systems. The decision-making process described in the OECD project is contrasted with the conventional approach to transport policy-making in Figure 3-1.

![Figure 3-1 Contrasting conventional transport policy-making with the OECD Environmentally Sustainable Transport (EST) approach](adapted from OECD 2002, p. 14 (OECD Working Group on Transport, 2002))
The policies identified by the working group were organised into five main types:

1. Fiscal measures (fees and subsidies)
2. Regulatory policies
3. Both fiscal and regulatory
4. Investment by government
5. Educational and hortatory
6. Changing institutional structures

The principles, policy clusters and decision-making process emerging from the OECD work on environmentally sustainable transport provide a useful framework for considering the evolution of transport policy-making over a similar period in New Zealand and the Auckland region.

3.2. Evolution of transport policy-making in New Zealand

This section briefly describes developments in transport policy-making in New Zealand and in Auckland over the past decade, in the context of transport legislation. The first and second versions of the National Land Transport Strategy (NZTS) are considered against the OECD environmentally sustainable transport framework described above. The accompanying statements of funding are also discussed, as they reflect the actions taken in response to strategic objectives. I have analysed the last three Auckland Regional Land Transport Strategies (ARLTS) in the same way. These analyses are based in part on submissions I have made on behalf of the School of Population Health to both the national and regional strategies since 2005, as part of this research. They also reflect my experience as a public health representative on the ARLTS Technical Advisory Committee in the development of the 2010 ARLTS⁸; and as co-author of a Health Impact Assessment of the draft 2010 strategy⁹.

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⁹ The final report from this Health Impact assessment is available from http://www.moh.govt.nz/moh.nsf/indexmh/hiasupportunit-completed#arlts
3.2.1. Land Transport Legislation


The Land Transport Act (Land Transport Act (as enacted), 1998) allowed the Ministry for Transport for the first time to develop a national transport strategy, with goals, objectives and measurable targets (s170(1-2)). The Act stipulated a process of consultation, providing for an opportunity for people to make submissions on the proposed strategy (s171(1)). The Act also set out requirements for regional councils to develop regional transport strategies. Under the Act, regional strategies were for identifying future transport needs, and for responding to those needs in a safe and cost effective manner, while taking account of the effect of the transport system on the environment (s175(1-2)). Regional strategies were also to include how different modes could contribute to national objectives (s175(2)). These stipulations reflected the conventional forecasting, provision and mitigation policy-making approach described above (see Figure 3-1). The Act required each regional council to establish a regional land transport committee, to prepare the regional strategy (s178(1)). Suggested representation on the committee includes “all or any” of: commercial and private road users; railway and public transport users and operators; and cycling and pedestrian representatives (s178(2)).

The Land Transport Management Act 2003 (Land Transport Management Act, 2003 [LTMA]) replaced much of the Land Transport Act 1998, establishing the national land transport fund, guiding planning, and stipulating the process for funding decisions. The LTMA took its purpose from the first New Zealand Transport Strategy that had considered all transport modes (Ministry of Transport, 2002), as well as incorporating its five objectives into legislation. The purpose of the LTMA is “…to contribute to the aim of achieving an affordable, integrated, safe, responsive and sustainable transport system” (s3(1)). National and regional organisations undertaking transport activities must take into account how those activities contribute to the following five objectives (s12(3)):

1. Assisting economic development
2. Assisting safety and personal security
Chapter 3 – Policy Analysis

3. Improving access and mobility
4. Protecting and promoting public health
5. Ensuring environmental sustainability

These objectives conflate safety from crime with safety from injury, as well as continuing the longstanding separation of road traffic injury safety from other aspects of public health in transport policy and funding. Safety activities are also specifically exempted in the Act from taking the other objectives into account (s12(4)). This exemption separates injury from other aspects of public health, placing one kind of harm from transport activities (road traffic injury and death) above other harms (such as morbidity and mortality caused by motor vehicle air pollution) as well as creating a shortcut to activity funding through a justification of improving safety. The public health objective includes both health protection and promotion. This represents a transition from only mitigating the unintended negative health consequences of transport activities (such as air pollution and injury) to considering the potential for transport activities to contribute positively to health (for example by encouraging transport-related physical activity). Social equity was considered specifically in a separate section, which states that the needs of people who are “transport disadvantaged” (s35) are required to be considered by all agencies. However, transport disadvantage was not further defined in the Act.

The provisions relating to the development of national and regional transport strategies remained from the Land Transport Act 1998, with further stipulations in both the LTMA 2003 and in an amendment to the Land Transport Act (Land Transport Amendment Act) about representation in the development of regional strategies, including a stronger requirement for each regional council to “appoint a sufficient number of persons to represent a balance of the objectives” (s7(2A)) described above, as well as “cultural interests” (LTMA 2003 Schedule 6). These people must come from the wider regional community rather than from within local government (s7(2B)). Schedule 6 of the LTMA 2003 added the requirement for regional land transport strategies to include a “demand management strategy”, which was not further defined. Changes to the Local Government Act 2002 at this time also required councils in the Auckland region to integrate land transport and land use planning, in keeping with the integrated planning principles developed by the OECD and described above (Section 3.1).
In 2008 a number of significant changes were made to the LTMA (Land Transport Management Amendment Act 2008, [LTMAA]). The previous separation of transport functions across different national agencies was now resolved through the creation of a single New Zealand Transport Agency (NZTA) (s93). Transport revenue became fully hypothecated (s6), meaning that all road user charges, registration charges and fuel excise taxes are now dedicated to land transport. It became mandatory for the Ministry of Transport to “prepare and adopt a national land transport programme for the following three financial years” (s19A), the Government Policy Statement on transport (transport GPS). Because the transport GPS is mandatory and sets out funding allocations, while the national strategy remains optional, the policy statement has started to play a stronger strategic role in guiding regional land transport strategies and programmes of action (Ministry of Transport, 2008a). This is also highlighted by the legislative requirements in the LTMAA: although the NZTA must “take into account” (s72(1-2)) the national transport strategy, it is required to “give effect to” the transport GPS. In contrast to the national and regional detailed requirements for consultation amongst a wide range of stakeholders, there is no legislative requirement for consultation on the transport GPS. This sets up a tension for regional councils between the long-term consultative planning required for regional strategies and the short-term political funding cycle determined in the transport GPS.

3.2.2. New Zealand Transport Strategy (NZTS)

The NZTS 2002 (Ministry of Transport, 2002) was the first national strategy to recognise all transport modes, acknowledging that the heavy investment in the road network, and consequent growth in motor vehicle use, had brought with it environmental and health consequences. The vision and objectives set out in the strategy were later enshrined in legislation through the LTMA, and have been described above (Section 3.2.1). The objectives in both the NZTS 2002 and the LTMA are implicitly prioritised, with economic development at the top of each list, and environmental sustainability at the bottom. This is in direct contrast to the hierarchy of principles developed by the OECD, which has access and equity at the top and economic wellbeing at the bottom. The strategy followed a conventional transport policy-making approach, assessing problems arising from current activity and attempting to mitigate and address those problems. Although current trends were quantified for each objective in lists of key facts about transport, no quantifiable targets were developed for objectives, and neither were specific
strategies discussed that would meet the objectives. Many of the initiatives described to meet objectives involved research and further strategy development. The strategy signalled prioritisation of funding to five areas: severe congestion, public transport, walking and cycling, regional development and alternatives to roads, and safety.

In 2007, the New Zealand government developed its own Sustainable Transport discussion document to enhance the participation of the public and other stakeholders in the development of an updated national strategy (Ministry of Transport, 2008b, [NZTS 2008]). In many ways the process of development and the content of the NZTS 2008 were closer to the process of decision-making for environmentally sustainable transport outlined by the OECD (Figure 3-1). There was greater participation of stakeholders earlier in the process, and the long-term vision was accompanied by quantified targets. The participation of stakeholders led to a re-ordering of the five transport objectives in the strategy to:

1. Ensuring environmental sustainability
2. Assisting economic development
3. Assisting safety and personal security
4. Improving access and mobility
5. Protecting and promoting public health

Specific strategies were identified to meet each target and a set of monitoring indicators was developed. For the greenhouse gas emissions reduction target there was also some evidence of a backcasting approach, whereby the contributions of managing travel demand, mode shift, vehicle fleet technological changes and biofuels were modelled to develop interim and long-term strategies. A significant interim strategy to manage travel demand at peak times was the investment in measures to increase the uptake of school and workplace travel plans, as well as rideshare projects.

The contributions of both New Zealand Transport Strategies to the environmentally sustainable transport principles developed by the OECD are summarised below in Table 3-2.
## OECD Principle

<table>
<thead>
<tr>
<th>OECD Principle</th>
<th>NZTS 2002</th>
<th>NZTS 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Access</strong></td>
<td>Review of access to public transport planned (p. 30)</td>
<td>Improved access to enable all New Zealanders to participate fully in society a goal (p. 62)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contribution of access to goods and services to wellbeing acknowledged (p. 65)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quantified targets to increase public transport use and increase walking and cycling trips (p. 17)</td>
</tr>
<tr>
<td><strong>Equity</strong></td>
<td>Needs of rural people, elderly, children and people with disabilities mentioned (pp. 27-28)</td>
<td>Acknowledged inequities in mode choice and affordability, including for rural people and those with disabilities (p. 62)</td>
</tr>
<tr>
<td></td>
<td>Inter- and intra-generational equity not mentioned</td>
<td>Signalled further research and development of targets to address transport disadvantage (p. 71)</td>
</tr>
<tr>
<td><strong>Individual and community environmental responsibility</strong></td>
<td>Achieving environmental sustainability requires reorientation of policy as well as individual decisions (p. 43)</td>
<td>Strategic approach combines policy and regulation with individual behaviour change (p. 30)</td>
</tr>
<tr>
<td><strong>Health and safety</strong></td>
<td>Importance of injury, personal security, air pollution, noise and water pollution all recognised (pp. 18-22, 35)</td>
<td>Quantified targets to reduce road deaths and serious injuries (p. 17)</td>
</tr>
<tr>
<td></td>
<td>Potential for transport to promote health through physical activity and social interaction also recognised (p.35)</td>
<td>Qualitative targets to reduce exposure to noise and air pollution (p. 17)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quantified target to increase walking and cycling (p. 17)</td>
</tr>
<tr>
<td><strong>Education and public participation</strong></td>
<td>The need for greater transparency and participation recognised (p. 51)</td>
<td>A process of stakeholder engagement and meetings to discuss an early draft were undertaken in development of the strategy (p. 15)</td>
</tr>
<tr>
<td><strong>Integrated planning</strong></td>
<td>The importance of destinations within reach for improving access was briefly alluded to (p. 27)</td>
<td>Integrated planning is integrating transport and land use, as well as integrating across transport modes (p. 34-35)</td>
</tr>
<tr>
<td></td>
<td>Investigation of more sustainable settlement forms a planned initiative to improve environmental sustainability (p. 46)</td>
<td>Land use identified as an important long-term influence on transport demand (p. 34)</td>
</tr>
<tr>
<td></td>
<td>No mention of integrated planning</td>
<td>Signalled future requirements for alignment between transport projects and land use plans (p. 34)</td>
</tr>
</tbody>
</table>
### Table 3-2 Analysis of national transport strategies against OECD EST principles

<table>
<thead>
<tr>
<th>OECD Principle</th>
<th>NZTS 2002</th>
<th>NZTS 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land and resource use</td>
<td>Contribution of land transport to energy use identified (p. 43)</td>
<td>Role of transport in use of non-renewable resources, land contamination, loss of biodiversity and landscape impacts identified (p. 52)</td>
</tr>
<tr>
<td></td>
<td>High levels of land use by transport infrastructure identified (p. 44)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Develop fuel consumption labelling for selected road vehicles (p. 46)</td>
<td>Specific target to increase indigenous vegetation on Crown transport land (p. 17)</td>
</tr>
<tr>
<td></td>
<td>Implement of fuel efficiency labelling for imported cars (p. 46)</td>
<td></td>
</tr>
<tr>
<td>Pollution prevention</td>
<td>Contributions of land transport to greenhouse gas emissions, air and water pollution identified (pp. 35 &amp; 44)</td>
<td>Target to halve per capita greenhouse gas emissions by 2040 through quantified and qualitative targets to change freight modes, deploy electric vehicles, reduce single occupancy travel, improve fuel efficiency and increase public transport, walking and cycling (pp. 50-51)</td>
</tr>
<tr>
<td></td>
<td>Research initiatives for noise, water and air pollution identified (p. 38)</td>
<td></td>
</tr>
<tr>
<td>Economic wellbeing</td>
<td>Transport system plays a crucial role in economic development (p. 11)</td>
<td>Transport a principal factor in supporting economic growth through efficiency of supply chains, attracting transport workforce, supporting Auckland becoming a world-class city and supporting tourism and export industries (p. 55)</td>
</tr>
<tr>
<td></td>
<td>Future possibility of full cost accounting hinted at (p. 12)</td>
<td>Qualitative target to improve reliability of journey times and reduce journey times on critical routes (p. 17)</td>
</tr>
<tr>
<td></td>
<td>Consideration of congestion pricing to reduce congestion (p. 15)</td>
<td>Quantified targets to reduce single occupancy trips and shift freight to shipping/rail to reduce congestion (p. 17)</td>
</tr>
</tbody>
</table>

Despite the increasing convergence of national strategic transport planning with the OECD principles, most of the national land transport budget continues to be spent on maintenance and renewal of existing roads, as well as significant new road development. My own analysis of annual spending of the National Land Transport Fund suggests that the strategic changes have led to a gradual modest reduction in the proportion spent on roads (to about three quarters of the fund in 2009/2010, accompanied by increases in the
proportion spent on public and active transport (New Zealand Transport Agency, 2011)). Changes over the past decade by activity class are shown in Figure 3-2.

![Figure 3-2 National Land Transport investment by activity class 2000-2010 (New Zealand Transport Agency, 2011)](image)

Between the development of the NZTS 2002 and the release of the first transport GPS there was a change of government. The new Minister of Transport released his first transport GPS in 2009 (Ministry of Transport, 2009a). In the foreword to the statement, the Minister indicated the government’s priority for investment as “economic productivity and growth in New Zealand” and signalled the investment policy’s reversion to a traditional “predict and provide” approach:

“The GPS aligns investment in the land transport sector more closely with this priority. Further, the GPS closely reflects the modal choices that are realistically available to New Zealanders. Approximately 70 percent of all freight in New Zealand goes by road, and 84 percent of people go to work...
by car, truck or motorbike, so we need good roads to move freight and people.” (Ministry of Transport, 2009a) (p.1)

Although there continues to be a legislative requirement for the transport GPS to align with the NZTS, a diagram of strategic documents in the GPS omits the NZTS (p.6). Although the NZTS is acknowledged in the transport GPS, the statement explicitly disagrees with the direction in the national strategy, in particular considering that “moving too quickly on modal shift will have a negative impact on environmental and economic efficiency” (p. 11). The short to medium term goals the government expects to achieve with its investments are heavily weighted towards economic growth, with an expected trickle-down effect: “[i]n pursuing economic growth and productivity, the government also expects to see progress on other objectives” (p.10). The funding allocations are consistent with these retrograde strategic directions, with 76% of the total budget to be spent on maintaining, renewing and building new state highways and local roads. The construction, maintenance and renewal of state highways are particularly favoured, gaining 53% of the total budget. Public transport infrastructure and services are allocated less than 10% of the budget.

In summary, there is a persistent mismatch between the highest level strategic goals, the allocation of funding, and therefore the resulting implementation of transport policy. A number of transport policy commentators have criticised this failure to realise the sustainable transport goals enshrined in the legislation. In particular, the transport planning process has been criticised for lacking the ability to envisage a wide enough range of alternative futures and identify the policies that would be required to achieve them (Furnish & Wignall, 2009). The targets in the NZTS 2008 have therefore been disregarded at the highest political level as impossible to achieve or “aspirational” (GPS 2009 (Ministry of Transport, 2009a), p. 11). Although many of the principles of environmentally sustainable transport outlined by the OECD are reflected in the highest level strategic documents, processes to educate, empower and involve communities in transport planning remain absent from the national policy-making process. The most recent changes to the land transport legislation have invested the greatest statutory power in the Government Policy Statement even though (in contrast to other strategic documents recommended and required in the legislation) there is no consultative requirement for the transport GPS under the law.
3.2.3. Auckland Regional Land Transport Strategy (ARLTS)

Regional strategic transport policy in Auckland has until very recently followed a trajectory similar to national strategies and policies. This reflects the legislative requirement for regional policies to be aligned with national strategic directions.

The 2005 ARLTS (Auckland Regional Council, 2005) was the first Auckland transport strategy prepared under the Land Transport Management Act 2003. The strategy specifically recognised the OECD Environmentally Sustainable Transport documents as significant in an international policy context, as well as emphasising New Zealand’s commitment to reducing greenhouse gas emissions through its ratification of the Kyoto Protocol (p.128). The 2005 strategy acknowledged limitations in its ten year focus, and signalled the development of a longer term strategy to follow soon after its release (p. 12-13). The 2010 ARLTS (2010a) therefore has a 30-year time horizon. A conventional transport modelling approach\textsuperscript{10} was used in the development of both strategies, with a number of policy scenarios tested for effectiveness at meeting specific targets using forecast modelling (2009). Table 3-3 assesses both policies against the OECD sustainable transport principles.

\textsuperscript{10} A four-step Land Use and Transport Study (LUTS) involving forecasting of land use and trip production; trip distribution; division of trips from origin to destination between existing and proposed modes; and assignation of trips to routes (Lay, 2005)
<table>
<thead>
<tr>
<th><strong>OECD Principle</strong></th>
<th><strong>ARLTS 2005</strong></th>
<th><strong>ARLTS 2010</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Access</strong></td>
<td>Networks exist so people can get around easily and safely, access work, education and shops to meet social, economic and cultural needs (p. 39)</td>
<td>Networks exist so people can get around easily and safely, access work, education and shops to meet social, economic and cultural needs (p. 25)</td>
</tr>
<tr>
<td><strong>Equity</strong></td>
<td>Aim: everyone to participate in society Special attention for those who find it difficult to travel independently (p.40) Role of public transport in providing basic accessibility for people with disabilities (p.48) Qualitative targets to enable pedestrian and cyclist access to all local destinations easily and safely, and to provide people with disabilities the ability to participate more fully in society (p.40)</td>
<td>Aim: everyone to participate equitably in society (p. 21) Treaty of Waitangi acknowledged as important (p. 18) Special attention for people with disabilities/limited travel choices because of socioeconomic status, ethnicity or poor provision of services (p. 25) Quantified target to increase disability access to public transport (p. 26) Qualitative targets to improve perceived affordability and accessibility of walking, cycling, public transport, (pp.25-26)</td>
</tr>
<tr>
<td><strong>Individual and community environmental responsibility</strong></td>
<td>Role of transport system in contributing to adverse environmental effects and supporting energy conservation (p.41)</td>
<td>Transport system and motor vehicles as major source of adverse environmental effects (p.28)</td>
</tr>
<tr>
<td><strong>Health and safety</strong></td>
<td>Physical, social, chemical and psychological effects of transport on health identified (p.33) Qualitative targets to reduce vehicle emissions, increase active transport, reduce injury, the effects of noise and vibration, and maximise the health benefits of travel (pp. 39, 41)</td>
<td>Quantified targets to reduce road deaths and serious injuries; increase perception of safety; reduce annual air quality standard exceedances; increase walking and cycling mode share; and increase distance walked per day (pp. 25-27) Qualitative targets to reduce proportion of drivers exceeding the speed limit, improve attitudes to road safety; improve personal security; reduce annual air pollutant concentrations; and improve local neighbourhood walkability (pp.25-27)</td>
</tr>
<tr>
<td>OECD Principle</td>
<td>ARLTS 2005</td>
<td>ARLTS 2010</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Education and public</td>
<td>Representatives of the five legislative transport objectives on policy</td>
<td>Representatives of five transport objectives on policy development committee</td>
</tr>
<tr>
<td>participation</td>
<td>development committee (p. 11)</td>
<td>committee</td>
</tr>
<tr>
<td></td>
<td>Single representative of cultural interests (Māori) on policy development</td>
<td>Single representative of cultural interests (Māori) on policy development committee</td>
</tr>
<tr>
<td></td>
<td>committee</td>
<td>committee</td>
</tr>
<tr>
<td></td>
<td>Effective community participation important for ownership of decisions</td>
<td>Māori need to have active participation in resource planning and management – specific policy to improve participation of Māori in transport decision-making</td>
</tr>
<tr>
<td></td>
<td>(p.11)</td>
<td>(p.114)</td>
</tr>
<tr>
<td></td>
<td>Early region-wide consultation through newsletter and feedback process 1</td>
<td>Early consultation of 300 specific stakeholders (p.15)</td>
</tr>
<tr>
<td></td>
<td>year prior to draft strategy (p.11)</td>
<td>Submissions accepted on draft strategy</td>
</tr>
<tr>
<td></td>
<td>Submissions accepted on draft strategy</td>
<td>Improved public information about costs and benefits of choices part of</td>
</tr>
<tr>
<td></td>
<td></td>
<td>travel demand management policies</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(p.102)</td>
</tr>
<tr>
<td></td>
<td>Improved public information about costs and benefits of choices part of</td>
<td>Specific information and education policies to achieve behaviour change,</td>
</tr>
<tr>
<td></td>
<td>travel demand management policies</td>
<td>including information about environmental and health impacts of transport</td>
</tr>
<tr>
<td></td>
<td>(p.102)</td>
<td>choices (p. 88-89)</td>
</tr>
<tr>
<td>Integrated</td>
<td>Integration between land use and transport signalled to support well</td>
<td>Integration between land use and transport planning undertaken to ensure</td>
</tr>
<tr>
<td>planning</td>
<td>designed urban growth (p. 42)</td>
<td>they are mutually supportive (p. 77)</td>
</tr>
<tr>
<td></td>
<td>Integration between modes considered to support more multi-modal trips</td>
<td>Specific policies to support integration between modes and between public</td>
</tr>
<tr>
<td></td>
<td>(p.52)</td>
<td>transport providers (p. 112)</td>
</tr>
<tr>
<td></td>
<td>Requirement to undertake integrated transport assessments (public health</td>
<td>Requirement to undertake integrated transport assessments (public health and</td>
</tr>
<tr>
<td></td>
<td>and environmental effects) for new significant trip generating activities</td>
<td>environmental effects) for new significant trip generating activities (p.</td>
</tr>
<tr>
<td></td>
<td>(p. 115)</td>
<td>115)</td>
</tr>
</tbody>
</table>
### Land and resource use

<table>
<thead>
<tr>
<th>OECD Principle</th>
<th>ARLTS 2005</th>
<th>ARLTS 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualitative outcomes include supporting and instigating growth within higher density centres; improving walking and cycling in these centres; integrated land use and transport to manage urban growth pressures in areas where growth is not planned (p.43)</td>
<td>Focusing on cycling, walking and public transport seen as enabling higher density mixed use centres (p.78) to reduce development outside the metropolitan urban limit (p.31)</td>
<td>Qualitative target to improve protection of sites with historic, environmental and cultural value (p.28)</td>
</tr>
<tr>
<td>Qualitative target to protect sites and areas of natural and cultural heritage (p.42)</td>
<td>Qualitative targets to reduce the volume of waste from transport projects and increase volume of recycled materials (p.29)</td>
<td></td>
</tr>
<tr>
<td>Qualitative target to reduce consumption of non-renewable energy and resources (p.42)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Pollution prevention

<table>
<thead>
<tr>
<th>OECD Principle</th>
<th>ARLTS 2005</th>
<th>ARLTS 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualitative targets to reduce CO₂ emissions; improve stormwater quality; and reduce vehicle emissions (pp.41-42)</td>
<td>Quantified target to halve per capita transport greenhouse gas emissions by 2040 (p.28)</td>
<td>Qualitative target to improve stormwater quality (p.28)</td>
</tr>
<tr>
<td></td>
<td>Quantified targets to improve air quality (pp.27-28)</td>
<td></td>
</tr>
</tbody>
</table>

### Economic wellbeing

<table>
<thead>
<tr>
<th>OECD Principle</th>
<th>ARLTS 2005</th>
<th>ARLTS 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic development includes all people participating in economy; improved links between business areas and to export and import centres; promotion of business and tourism; predictable travel times (pp.38-39)</td>
<td>Economic development relates to supporting business growth, productivity and competitiveness (p.23)</td>
<td>Economic efficiency includes improving the use of the existing transport network (p.32)</td>
</tr>
<tr>
<td>Road pricing recognised as important to manage travel demand in the future (pp.86-87)</td>
<td>Quantified targets to maintain congestion levels and journey times; improve resilience of the system and improve transport contribution to competitiveness (p.24)</td>
<td>Introduction of comparative project evaluation to account for benefits to employment and productivity (p.10)</td>
</tr>
</tbody>
</table>

| Table 3-3 Analysis of Auckland regional transport strategies against OECD EST principles | | |
The 2010 regional strategies set specific quantified targets for many objectives for the first time, with detailed consideration of available indicators of whether objectives were likely to be met under different policy scenarios. These changes represented a move towards a decision-making process using environmentally sustainable transport principles (see Figure 3-1). The 2005 ARLTS described a qualitative vision, and the 2010 ARLTS extended this to a refined and quantitative vision of what a sustainable transport system would look like for the Auckland region. Scenario testing was used for both strategies in an attempt to determine a policy scenario to secure the vision. However, limitations in the conventional modelling approach, coupled with a lack of political will, meant that only a small number of scenarios could be tested for their effectiveness at meeting objectives. None of the scenarios tested for either strategy was able to achieve the changes required to secure the agreed vision, and the decision-making process lacked the flexibility to return to the vision, understand trade-offs and undertake a true backcasting exercise. Implicit trade-offs were therefore made at a political level, and policy scenarios were accepted that were unable to meet the stated objectives in both cases.

The strategic option chosen in the current strategy, and the planned funding allocations associated with it demonstrate a divergence between regional and national policy and funding directions. The first Government Policy Statement outlined above (Section 3.2.2) was released during the preparation of the 2010 RLTS, but the final regional strategy persisted in giving weight to all the legislative transport objectives, and the funding allocation provides a greater proportion to public transport and travel demand management. The funding allocations indicated in both the 2005 and 2010 strategies are shown in Figure 3-1 below, demonstrating the move towards greater public transport funding.
Persistence with such a divergent strategy may in part have been due to the consultation process undertaken for both the 2005 and 2010 strategies. Wide public consultation on an early draft of the ARLTS 2005 was undertaken a year before it was adopted and included a lay summary of the strategic options accompanied by a self-completion survey, mailed to all households in the Auckland region (2005). There were 3200 responses to the survey (Campbell, 2009). In addition, Māori regional stakeholders were specifically invited to
take part, by mail and through face to face meetings (Campbell, 2009). This early widespread consultation, coupled with the submissions processes for both strategies, confirmed widespread public support for the provision of improved public transport (Campbell, 2009). In addition to the legislated consultation and submissions process, the preparation of the 2010 RLTS included a Health Impact Assessment (HIA) commissioned jointly by the regional council and the regional public health unit (Field, et al., 2009). Undertaken in 2008, the HIA included both a conventional approach with stakeholder workshops, and a Whānau Ora HIA specifically to explore how the strategy could improve Māori health and reduce Māori health inequities. The recommendations from the HIA adduced high level stakeholder support for the most radical strategic options suggested by the draft documents; those which maximised investment in public transport and “travel demand management”.

Unlike any previous regional or national strategies, the 2010 ARLTS included an agreed policy implementation hierarchy (p.77). The hierarchy prioritises demand side policies that are likely to have a long-term effect on transport patterns and system management, before considering the provision of further new infrastructure. The demand side policies described are all aspects of travel demand management. Travel demand management has been included as a separate funding activity class in both the 2005 and 2010 strategies, with an increasing emphasis placed on its importance over time. Because of its relevance to influencing commuting patterns, travel demand management and travel planning are described further in the next section.

3.3. Travel demand management and workplace travel plans: policy case study

The 2005 ARLTS recognised that “Aucklanders’ dependence on the car makes it difficult to supply transport infrastructure to cope with increasing demand” (p.97). Not only was there a legislative prerogative for travel demand to be part of the strategy in the Land Transport Act (Land Transport Amendment Act, 2004), but it was also seen as an essential response to the unsustainable growth in demand for car travel. The strategy proposed a definition of travel demand management as:

“A set of tools to offer people better travel information and opportunities and help people choose to reduce their need to travel especially by car”

(p.97)
The set of tools included reducing the need to travel through changing land use and telecommunications; providing for travel choices through improved public transport services, construction of walking and cycling networks and re-allocation of road space; influencing travel choices through organisational and community travel planning; increasing the cost of parking, congestion pricing and road tolling. However, the lack of adequate funding provided in the strategy for improving public transport services or cycling and walking networks, and the political unacceptability of road pricing, meant that much of the emphasis was on influencing travel choices through voluntary behaviour change. This emphasis was further strengthened by the policy hierarchy introduced in the 2010 ARLTS, which gives priority to demand management activities over improvements in infrastructure.

The emphasis on voluntary behaviour change led to the development of the region’s first Sustainable Transport Plan in 2007 (2007) to implement this aspect of the strategy. The definition of sustainable transport provided in the plan has a narrow focus when compared with the OECD definition provided earlier (Section 3.1), and is described as: “Working with people and their communities to improve travel opportunities and to encourage people to make fewer car journeys” (p.5). The scope of the plan was to fund improvements to walking and cycling networks and influence travel choices through school and workplace travel plans, and neighbourhood accessibility plans. Changing people’s transport patterns in the trip to work through workplace travel plans was given particular emphasis in both the ARLTS 2005 and the Sustainable Transport Plan. Workplace travel plans were expected to achieve a 12% reduction in car trips to work or study by 2016 (ARLTS 2005 p.103). The 2010 ARLTS sets more modest targets for workplace travel plans, aiming for a 24% reduction in car trips to work in the regional growth centres by 2041 (Robles & Van-Roon, 2009).

Workplace travel plans (WTPs) are currently used by local governments and organisations across many high income countries for encouraging public and active transport use in the trip to work and study. They are behaviour change programmes undertaken by businesses and institutions, sometimes accompanied by modest alterations to the local physical environment to improve the safety and convenience of active and public transport. Although not typically labelled as such, they can be considered as complex health promotion interventions. In other words they are multi-faceted interventions at the level of the individual, the organisation and the neighbourhood,
expected to have a range of outcomes for health promotion. A wide range of activities is considered in the context-dependent design of workplace travel plans, making them heterogeneous interventions. These activities may include any number of the following (Cairns, et al., 2004):

- Personalised education to improve knowledge about transport options
- Financial incentives such as subsidised public transport fares or bicycle vouchers
- The removal of financial incentives for car travel such as free parking spaces or company cars
- Improving facilities for cyclists and pedestrians such as provision of bicycle shelters, lockers, drying rooms and showers, creating improved pedestrian access
- Co-ordination of co-operative schemes such as car pooling or cycling groups

Although the most common interventions involve personalised education, evaluation of schemes suggests that the most effective interventions are removing financial incentives for car use such as free parking (Cairns, et al., 2004).

The emphasis on WTPs in policy documents and discussions led me to consider their potential to effectively achieve health and sustainability outcomes, with a view to undertaking comprehensive quantitative modelling to demonstrate the likely outcomes of their region-wide uptake in Auckland. The first step in this analysis was to undertake a systematic review of workplace travel plans to determine their likely effectiveness. This systematic review is described in the next section.

3.4. Effectiveness of workplace travel plans: systematic review

The systematic review to consider the effectiveness of workplace travel plans was undertaken as part of a larger combined review of the effectiveness of organisational travel plans, which also included those undertaken in schools and universities. The work for the combined review was shared equally by Jamie Hosking (JH) and me, with Jennie Connor, Chris Bullen and Shanthi Ameratunga (SA) as co-authors. The review was registered with the Cochrane Injuries Group and published in the Cochrane Library of Systematic Reviews in 2010 (Hosking, Macmillan, Connor, Bullen, & Ameratunga, 2010).
An adapted version of the published review is reported here, limited to the findings relating to workplace travel plans.

Prior to this review evidence was limited for the effectiveness of workplace travel plans at improving health or reducing car use. A commonly cited review of organisational travel plans has suggested they have the potential to reduce car trips to work or school by 8-15% (Cairns, et al., 2004). However, a systematic review of all interventions to promote walking and cycling concluded that evidence for the effectiveness of institutional interventions was not convincing (Ogilvie, Egan, Hamilton, & Petticrew, 2004). Furthermore, there may be health risks associated with workplace travel plans, including exposing cyclists and pedestrians to a higher risk of injury. This is particularly true in urban environments that are not planned to accommodate a range of transport modes, and where rapid motorization has not been accompanied by infrastructure to protect vulnerable road users.

The health equity implications of workplace travel plans depend on the way they are implemented. For example, widespread support for walking and cycling is likely to improve equitable access to employment. However, there is emerging evidence from the school travel planning literature that such interventions are more likely to be implemented in high income communities (D. Collins & Kearns, 2005) which could increase social disparities.

We therefore conducted a cross-disciplinary Cochrane systematic review to identify the best available evidence for the effectiveness of workplace travel plans in reducing car travel and improving health.

3.4.1. Methods

We conducted the review in accordance with a peer-reviewed protocol published by the Cochrane Collaboration (Hosking, Macmillan, Connor, Bullen, & Ameratunga, 2006).

Criteria for inclusion of studies

For this analysis I have included randomised controlled trials and non-randomised before-and-after observational or experimental studies of interventions to change travel behaviour in a workplace setting. To be included in this review the intervention must have aimed to reduce car use and increase walking, cycling or public transport use. We
considered any health outcomes to be relevant as a primary outcome and injury was of particular interest as a potential unintended adverse effect. Secondary outcomes included evidence of changes in physical activity or travel mode. Both of these secondary outcome measures could potentially be converted into measures of health benefit or climate mitigation using accepted assumptions about benefits of time spent walking and cycling, and reductions in vehicle kilometres travelled. We were also interested in whether the social distribution of health or travel mode outcomes had been considered or measured.

**Search strategy and study selection**

We searched 16 electronic databases across the transport, science, health, humanities and social science disciplines, without restrictions on date, status or language of publication. We applied a sensitive search strategy across databases reflecting a best practice approach to finding evidence about social interventions (Ogilvie, Hamilton, Egan, & Petticrew, 2005). We also searched a purposive sample of 26 websites, relevant conference proceedings and the reference lists of relevant articles and books. Full details of the search strategy are available at:


Two authors (AM and JH) independently assessed all titles and abstracts identified from the literature search. We retrieved full texts of articles considered potentially eligible, or which could not be excluded on the basis of the title or abstract. The same authors assessed all retrieved articles for inclusion. A third author (SA) was available to arbitrate discrepancies in assessment of inclusion.

**Data extraction and assessment of validity**

AM and JH independently extracted data about study design, results and risk of bias using a data extraction pro forma. Differences between authors were resolved by discussion and review with other authors. Where data were unavailable from the published report of a study, we contacted the study authors to request further information.

We assessed the quality of randomised controlled trials on the basis of concealment of allocation to intervention and control groups; randomisation; blinding of outcome assessment; and loss to follow-up. There are no standardised approaches for quality assessment in controlled before-and-after studies, however a number of tools have been evaluated for the assessment of methodological quality in non-randomised studies.
(Deeks, et al., 2003). Our assessment covered the four core items suggested by Deeks, et al. (2003): 1) assessing how participants were allocated; 2) establishing what attempts were made to identify important confounding factors; 3) describing any attempts made to balance intervention and control groups by design (including matching and evaluation of important differences); 4) noting if adjustments were made for confounding in the analysis.

We were unable to quantify the impact of methodological quality on reported results because of the heterogeneity of study design and interventions.

Selection bias is the most important source of bias in non-randomised studies of organisational travel plans. This is because studies evaluating the effectiveness of organisational travel plans were often an adjunct to the implementation of workplace travel plan policies by local government, using self-selection methods for recruiting schools and workplaces. Characteristics affecting the outcome were also likely to influence the self-selection of organisations for workplace travel plan interventions. Furthermore, we postulated that such “confounding by severity” was likely to cause an underestimate of the true effect of the intervention. For example, an organisation in an area with high levels of car congestion will be more likely to volunteer for a workplace travel plan intervention; however, the reasons for car congestion are likely to include factors such as low local walkability and poor access to public transport, which adversely affect the success of the workplace travel plan at reducing car use. A “proto-pathic” bias (Horwitz & Feinstein, 1981) may also be at work, whereby non-randomised studies may inappropriately find a positive association between having a workplace travel plan and an increased risk of injury to pedestrians and cyclists, if they are more likely to be introduced in organisations with the “early symptoms” of a dangerous environment (e.g. traffic congestion). Finally, performance bias is likely to be important in both randomised and non-randomised studies of workplace travel plan interventions. The application of workplace travel plan interventions is variable and context-dependent, with a high likelihood of contamination between intervention and control groups through proximity, as well as through the spontaneous uptake of workplace travel plan components by control organisations.

**Synthesis of data**
We summarised the primary and secondary outcomes reported for each of the included studies, tabulated the study design characteristics and outcomes of the studies and ranked them by study validity. Tabulation of study data and categorisation of validity items in this paper differ in presentation from the original report in the Cochrane Database of Systematic Reviews (Hosking, et al., 2010) although based on the same extracted data. We considered this format to be more appropriate for consideration of bias in non-randomised studies than the previous one, which was constrained by guidelines designed for assessing randomised controlled trials. The low overall internal and external validity and the wide heterogeneity in study design, interventions and outcomes, meant that meta-analysis could not be undertaken and we were limited to a descriptive analysis of the data.

3.4.2. Results

Searches of electronic databases and grey literature identified 9139 citations for screening and the full texts of 83 citations were retrieved for further consideration. Only five workplace travel plan studies, reported in three papers (Atherton, Scheuernstuhl, & Hawkins, 1982; Mutrie, et al., 2002; Sargeant, Carter, McSweeney, & Hughes, 2004), met the inclusion criteria (Figure 3-4). Sargeant, et al. (2004) reported multiple study arms, and these arms were included as separate studies in the analysis. Details of excluded studies can be found at:

Design of included studies

Four randomised controlled trials were included (Mutrie, et al., 2002; Sargeant, et al., 2004). Of these, three were arms of the Cambridgeshire Travel Choice Project (Sargeant, et al., 2004) and one of these arms included both random and non-random allocation components. The remaining study was a non-randomised before-after study (Atherton, et al., 1982). The four randomised controlled trials were conducted in the United Kingdom, and the before-after study in the United States. All the studies were conducted in urban areas, with adult participants of both genders. No studies reported the socioeconomic status or ethnicity of participants.

The methodological validity of most studies was poor, reflecting difficulties in designing robust studies of complex and variable socio-geographical interventions. The assessment of methodological validity of included studies is summarised in Table 3-4.
<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>Allocation</th>
<th>Baseline response rate</th>
<th>Completeness of outcome data addressed</th>
<th>Paired observations</th>
<th>Identification of confounding factors</th>
<th>Adjustment for confounding in design or analysis</th>
<th>Freedom from performance bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mutrie 2002</td>
<td>RCT</td>
<td>Automatic randomisation, allocation concealed</td>
<td>89%</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Sargeant 2004</td>
<td>RCT</td>
<td>Allocation methods not reported. Included a component of non-random allocation. No allocation concealment</td>
<td>95%</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Design: Yes Analysis: No</td>
<td>No</td>
</tr>
<tr>
<td>Addenbrooke</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Substantial baseline differences despite randomisation</td>
<td></td>
</tr>
<tr>
<td>Sargeant 2004</td>
<td>RCT</td>
<td>Alternate allocation from alphabetical list of names. No allocation concealment or blinding</td>
<td>70%</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Design: Yes Analysis: No</td>
<td>No</td>
</tr>
<tr>
<td>Council Car Park</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Substantial baseline differences despite randomisation</td>
<td></td>
</tr>
<tr>
<td>Sargeant 2004</td>
<td>RCT</td>
<td>Allocation methods not reported</td>
<td>95%</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Design: Yes Analysis: No</td>
<td>No</td>
</tr>
<tr>
<td>Council New Recruit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Substantial baseline differences despite randomisation</td>
<td></td>
</tr>
<tr>
<td>Atherton 1982</td>
<td>CBA</td>
<td>Self selection</td>
<td>65-93%</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 3-4 Summary of the validity assessment for included studies (RCT – Randomised Controlled Trial, CBA – Controlled Before-and-After Study)

Interventions and outcome measures

Interventions were heterogeneous and varied widely depending on the geographical, social, organisational and political context. Four of the five workplace studies reported very similar interventions, providing tailored advice and information to employees (Mutrie, et al., 2002; Sargeant, et al., 2004). The fifth study involved the adoption of a compressed work week (participants worked a normal number of hours over fewer days) (Atherton, et al., 1982).

Only one study (Mutrie, et al., 2002) measured any health outcomes. The health outcome measured was the health-related quality of life of participating employees, using the Short Form 36 (SF-36) instrument (Ware, Snows, Kosinski, & Gandek, 1993). All five studies measured changes in travel behaviour, but studies did not use a consistent measure for doing so: Mutrie, et al.(2002) measured net change in the distance walked; the three
studies reported by Sargeant, et al.(2004) measured percentage changes in single-occupant car use; and Atherton, et al.(1982) measured a net change in weekly distance travelled by car. No studies presented data on the distribution of effects by gender, ethnicity or socioeconomic status, and no studies considered the effects of the workplace travel plan intervention on the wider community.

**Effectiveness of workplace travel plans**

None of the studies provided convincing evidence of a population health benefit of workplace travel plans. A single randomised controlled trial of a workplace intervention for people in the “contemplation” or “preparation” stage of behaviour change towards active transport measured health outcomes directly (Mutrie, et al., 2002). The authors found a significant net improvement in SF36 scores in the intervention group for the Mental Health, Vitality and General Health subscales. Other subscales showed non-significant improvements.

With regard to the secondary outcomes we were interested in, net reductions in car use in intervention groups were reported by all five included studies. Mutrie, et al.(2002) was considered to be at lowest risk of bias of the included studies. This was a randomised control trial of advice and materials for individual participants promoting active and sustainable travel. In addition to the aforementioned improvements in quality of life, they reported a small net positive intervention effect on walking to work in a pre-selected group of participants who were already considering or preparing to change to an active commute. The increase in walking was 1.93 times higher in the intervention than the control group (95%CI 1.06-3.52). The other four studies were considered to be at high risk of bias.

The characteristics and results of included studies are summarised in Table 3-5.
### Table 3-5 Characteristics and effectiveness of included studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Intervention</th>
<th>Location</th>
<th>Participants</th>
<th>Sample size</th>
<th>Follow-up</th>
<th>Net reported effect</th>
<th>Net change in % car use from intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mutrie 2002</td>
<td>Interactive self-help active travel information</td>
<td>Scotland</td>
<td>Working adults</td>
<td>295</td>
<td>6 and 12 months</td>
<td>1500m net increase in weekly distance walked for those in “contemplation” stage of behaviour change</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Safety accessories</td>
<td></td>
<td></td>
<td>3 workplaces</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Delivered at baseline</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sargeant 2004 Addenbrooke</td>
<td>Personalised travel advice</td>
<td>England</td>
<td>Working adults</td>
<td>330</td>
<td>3 months</td>
<td>0.2% net increase in single-occupant car use in 5 days previous to survey</td>
<td>+0.2%</td>
</tr>
<tr>
<td></td>
<td>Travel information pack</td>
<td></td>
<td></td>
<td>1 workplace</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ongoing travel advice</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sargeant 2004 Council Car Park</td>
<td>Personalised travel advice</td>
<td>England</td>
<td>Working adults</td>
<td>281</td>
<td>3 months</td>
<td>14.7% decrease in single-occupant car use in 5 days previous to survey</td>
<td>-14.7</td>
</tr>
<tr>
<td></td>
<td>Travel information pack</td>
<td></td>
<td></td>
<td>1 workplace</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ongoing travel advice</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sargeant 2004 Council New Recruit</td>
<td>Personalised travel advice</td>
<td>England</td>
<td>Working adults</td>
<td>103</td>
<td>3 months</td>
<td>4.7% decrease in single-occupant car use in 5 days previous to survey</td>
<td>-4.7</td>
</tr>
<tr>
<td></td>
<td>Travel information pack</td>
<td></td>
<td></td>
<td>1 workplace</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ongoing travel advice</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atherton 1982</td>
<td>Introduction of compressed work week</td>
<td>USA</td>
<td>Working adults</td>
<td>748</td>
<td>Up to 12 months</td>
<td>18% net decrease in car mileage per week</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- four-day week</td>
<td></td>
<td></td>
<td>29 workplaces</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- nine-day fortnight</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 3.4.3. Review discussion

We identified few robust studies of workplace travel plans. There is currently no evidence for an effect of workplace travel plans on any of the expected health outcomes, except in one study of workers already preparing for or contemplating active travel (Mutrie, et al., 2002). There is also very limited evidence that they influence travel mode. Although all the studies we identified were behaviour change programmes, none included the multiple component, sustained interventions at local, organisation and individual levels that are generally referred to as workplace travel plans.
Chapter 3 – Policy Analysis

No studies were of interventions in low- or middle- income countries, nor did any studies report on the distribution of effects by socio-demographic factors such as gender, income or ethnicity.

Despite a sensitive and comprehensive search strategy there are likely to be studies of workplace travel plan effectiveness that were not identified. However, the reports identified in the grey literature alone were, without exception, judged to be of poor methodological quality. It is therefore unlikely that the identification of non-indexed studies would have changed the results of the review.

In the most cited review of workplace travel plans (Cairns, et al., 2004) the authors suggested likely reductions in car use in the order of 10-18%. On the basis of this, and other evaluations of low methodological quality, workplace travel plans have become a mainstay transport policy response to commuting car dependence in high income countries, particularly the UK. The results of this research suggest that the effectiveness of workplace travel plans is likely to be modest, and that more robust research is needed to establish whether they are useful for aligning health and environmental goals. The findings of the review are consistent with conclusions drawn by related studies of transport interventions (Morrison, et al., 2003; Ogilvie, et al., 2007).

Studies included in this review focused heavily on individual behaviour change aspects of workplace travel plans. Very little attention has been paid to removing the structural barriers to changing commuting behaviour, such as improving local walkability, providing cycling infrastructure or enabling access to public transport. Systemic structural interventions such as these are particularly important in cities where urban planning has failed to cater for a range of mode users, leaving pedestrians and cyclists at particular risk of injury.

The evidence to date also suggests that transport decision makers should be mindful of the potential for workplace travel plans to either widen or narrow existing environmental, health and social inequities, depending on their design and implementation.

Although businesses and public sector employers are likely to have a role in influencing the commuting behaviour of their employees, a wider suite of systemic interventions need to be considered for their potential to reduce car reliance in the trip to work. Any policy
level interventions need to be based on an improved understanding of the influences on commuting behaviour as well as the potential wellbeing and sustainability outcomes.

3.5. Summary

This chapter has analysed how the links between commuting and public health have been incorporated in transport policy in New Zealand and in Auckland. The reliance of current policy on individual behaviour change to achieve healthier commuting led me to analyse the effectiveness of workplace travel plans as a policy case study.

National and regional policies were analysed against the OECD Environmentally Sustainable Transport principles and process to consider the extent to which New Zealand has reflected international moves towards more sustainable transport policy. The OECD principles were chosen as a framework because they align closely with ecosystem health principles described in Chapter 2, bringing together public health, equity and environmental sustainability, as well as emphasizing participatory approaches to decision-making.

The analysis of national and regional legislation, strategies and policies demonstrates significant high level shifts in the philosophical shape of transport policy, including major changes in purpose and objectives that align closely with the OECD principles, including the need for greater public participation in decision-making. However, this high level thinking has not been successfully translated into the radical changes in funding and implementation that would be needed to meet these new objectives. The analysis suggests three reasons for this failure, as follows.

Despite a shift in process from conventional approaches towards the OECD environmentally sustainable decision-making model, successful backcasting has not yet been achieved, and therefore decision-makers have not been able to identify the policy levers needed to achieve targets. This may be explained by a scarcity of modelling approaches that improve on conventional forecasting transport models. Current conventional modelling approaches lack the flexibility and agility to consider an adequate range of policy levers in a typical policy development timeframe, and they incorporate environmental and health outcomes poorly (Davies, 2009).
Chapter 3 – Policy Analysis

The striking contrast in policy direction between the Government Policy Statement and Auckland’s strategic direction points to a second reason for the failure to meet objectives. The OECD principles emphasize decision-making processes that are participatory and empowering. Although early and improved consultation mechanisms are now enshrined in the legislation for regional transport decision-making, there is no consultation required in the legislation for the GPS. Opportunities for communities to contribute to regional decision-making are still heavily reliant on widespread passive mechanisms such as mail outs and conventional submission processes. Both these mechanisms tend to have low response rates, and favour older, more highly educated people, while ethnic minorities, youth and low income communities remain unrepresented. However, the persistent change in direction of the regional strategies despite retrograde national policy directives suggests that even minor improvements in public participation can strengthen policy directions and funding allocations towards more sustainable transport.

Thirdly, the systematic review of workplace travel plans indicates a lack of evidence for the effectiveness of chosen policy mechanisms. A considerable amount of attention has been given in recent policy documents to changing the transport behaviour of individuals undertaking short trips using travel demand management, particularly through organisational travel planning. This includes the use of workplace travel plans to improve the use of public transport, cycling and walking by commuters. I have considered workplace travel plans as a case study policy intervention, using best practice systematic review methods to explore whether they were likely to be effective at achieving healthier and more sustainable commuting patterns. The conclusions of the review suggest that strategies focusing heavily on behaviour change at the level of employing organizations (institutions and businesses) in the absence of widespread changes to the structure of the system are unlikely to have the effect desired in strategic plans. Furthermore they have the potential to cause unintended negative consequences for public health including increased injury to vulnerable road users.

Together these insights highlight a need to further understand effective policy levers for changing the trip to work, incorporating best evidence about the likely outcomes of a range of policy choices. Methods for increasing this understanding need to reflect sustainable transport principles, including being able to empower and involve a wide range of stakeholders in decision-making, and be agile enough to consider policy levers to
achieve quantified targets. This is in keeping with the broad definition of travel planning used in the 2005 ARLTS:

“The process of finding out why people make the travel choices they do, and what would persuade them to use their cars less.” (Auckland Regional Council, 2005, p. 101)

The process could be expanded to include understanding the likely health and sustainability outcomes of policy levers. This is the focus of the remainder of the thesis.
Chapter 4. Methodology

The analysis of transport policy in the previous chapter suggested that while there is a current trend towards including considerations of wellbeing and sustainability in transport policy, transport planning processes are currently inadequate to account for the complex commuting and public health outcomes described in the literature review. Furthermore, the analysis of New Zealand policies has revealed the existence of competing interests with unequal power in the planning process. Current practices do not allow for the alignment of these interests, the explicit discussion of underlying paradigmatic assumptions, or the discussion of explicit trade-offs to maximise the benefits of the transport system for public health. The analysis also suggested that dominant approaches to reducing car-dependent commuting through individual behaviour change programmes (such as workplace travel plans) were unlikely to achieve significant shifts towards healthy and sustainable commuting. A better understanding of the structural influences on commuting are needed to identify effective policy mechanisms.

The previous two chapters identify the need for a different approach to transport planning that could address some of these issues, by allowing for the integration of complex public health and transport relationships, demonstrating the likely effects of different transport policies on a range of outcomes and progressively incorporating community priorities into transport policy. These effects and outcomes are likely to differ between local, regional and national spatial scales. Addressing aggregate policy outcomes at a regional level will therefore require careful consideration of these differences by scale, as well as what constitutes “community”.

The conceptual basis for an ecosystem approach to health was introduced in Chapter 2 (Section 2.1). This approach can also provide a set of underlying methodological principles for considering how to improve the public health outcomes of transport policy. Researchers and practitioners from diverse disciplines, including environmental management, environmental health and health promotion, have been converging in their approaches to urban sustainability. Combining the conclusions of these overlapping disciplines, four principles for decision-making can be identified (De Plaen & Kilelu,
Chapter 4 - Methodology


1. Bringing together legitimate stakeholders and transdisciplinary knowledge
2. A systems perspective that places human wellbeing within an ecosystem framework and acknowledges complexity and uncertainty
3. Community participation in developing questions, decision-making and citizen control of solutions
4. A focus on inequalities and social justice

In particular, a number of authors have emphasised the importance of transdisciplinarity. This has been described in two different but complementary ways. Firstly, Max-Neef (Max-Neef, 2005) describes an integration of knowledge vertically through four hierarchies of academic knowledge: from basic sciences such as biology and physics; to purposive disciplines such as medicine and engineering; to normative disciplines such as planning and politics; and finally to values disciplines such as ethics and philosophy. He argues for more fundamental changes to thinking including greater systems thinking and holism (self-contained complex systems as more than the sum of their parts), as well as inductive reasoning that is able to deal with complexity and non-linearities. Like Max-Neef, Stokols, Harvey, Gress, Fuqua and Phillips (2005) consider the way scientists work together to integrate and extend theories, concepts and methods. However, others emphasise the importance of bringing different kinds of knowledge, including policy knowledge, community knowledge and academic knowledge, together on an equal footing (Häberli, et al., 2001; Kleiber, 2001). The “co-production” of “socially robust” knowledge to address complex issues of sustainability becomes the objective (Gibbons & Nowotny, 2001).

Ideally, the methods used for research to improve transport policy would attempt to address the four principles listed above. This chapter describes three methods currently used to integrate wellbeing into transport policy (health impact assessment, comparative risk assessment and participatory policy approaches) and their limitations when assessed against these principles. System dynamics (SD) modelling is then introduced, and participatory SD modelling is described as a methodology that holds promise in addressing many of the principles identified for improving decision-making for health, equity and sustainability.
Innovations in urban planning processes have tended to concentrate either on achieving a consideration of health in transport and other urban planning policy through Health Impact Assessment, or on achieving improved community participation in urban planning. These two approaches are discussed in more detail below.

**4.1. Health Impact Assessment**

Health Impact Assessment (HIA) is a decision-support tool that has emerged out of Environmental Impact Assessment methodologies (Joffe & Sutcliffe, 1997) together with developments in understanding of the wider determinants of health, which include the objectives in the Ottawa Charter for healthy public policy (Birley, 2011; Kemm, 2001). It is used to assist with both project and policy level decisions and has often been used to assess draft urban planning and transport policies. Although the definitions of HIA vary, at a policy level two essential features are widely agreed (Kemm & Parry, 2004): firstly its intent is to support decision-makers in choosing between policy options and secondly it does this by investigating the consequences for health of those options. All definitions of HIA have the common starting point of an existing policy or decision to be assessed (European Centre for Health Policy & WHO Regional Office for Europe, 1999; Kemm, 1999; Scott-Samuel, 1998). Methods for undertaking HIA vary widely along a spectrum from desktop literature reviews of the health effects taking 3-4 hours, to longer term projects involving evidence from several disciplines and stakeholder consultation (J. Parry & Stevens, 2001). Despite the promising principles of equity and participatory democracy set out, for example, in the Gothenburg Consensus in 1999 (European Centre for Health Policy & WHO Regional Office for Europe, 1999), the place of community participation in HIA is contested (Wismar, Blau, Ernst, & Figueras, 2007; Wright, Parry, & Mathers, 2005), and there are no agreed methods for how community knowledge should be incorporated into HIA recommendations (J. Parry & Stevens, 2001).

A recent review of effectiveness (Wismar, et al., 2007) argued that HIA can be successful at altering decisions in order to mitigate harms to health and increasing understanding of the links between policies and health. Others have argued that the strengths of HIA have so far been in relationship building (for example, Krieger, Northridge, et al., 2003), and that the systematic collection of evidence about wellbeing has not been methodologically strong enough to make sound predictions about the effects of decisions (J. Parry & Stevens, 2001; Thomson, 2008). The timing of HIA in the policy cycle has also been
identified as a problem (Wismar, et al., 2007). By design, the focus of HIA is on the adjustment of existing proposed policies rather than starting with a problem and developing innovative solutions that maximise wellbeing. However, experiences of HIA are not universally unsatisfactory. The HIA of the Mayor of London’s draft transport strategy (Mindell, Sheridan, Joffe, Samson-Barry, & Atkinson, 2004) achieved the successful alteration of the strategy in a short period of time. The HIA involved a single stakeholder workshop and resulted in the uptake of recommendations to increase active transport, prioritise interventions in deprived areas, reallocate space away from cars and measure the effects of the strategy on health. However, it was undertaken in what was acknowledged to be a very favourable political context.

While HIA can provide a useful starting point for introducing wellbeing and equity into policy, a persistent scarcity of methods hampers the incorporation of different kinds of knowledge and the creation of consensus based decisions. For instance, priority impacts on wellbeing identified by affected communities, such as stress or sense of safety, are often more difficult to quantify and find evidence for in the scientific literature (J. Parry & Stevens, 2001) and may therefore be ignored in the recommendations of an HIA. Assumptions made about the evidence of health effects are often implicit in the assessment, rather than being openly understood by all stakeholders.

The “health” language of HIA, as well as its separation from environmental, integrated or sustainability impact assessments, tends to lead to a narrow view of health and a ‘health trumps all’ (Krieger, Northridge, et al., 2003) approach, rather than incorporating health into the broader goals of public policy (which might better be described as wellbeing, equity and sustainability). The proliferation of different impact assessments, including environmental, social, health, sustainability, and equity, has led to competition for the time of decision-makers and a confusing lack of integration (Ståhl, 2010). More recent moves towards an integrated assessment in Europe have also been problematic, with competing interests creating a return to health, equity and the environment being excluded from consideration (K. E. Smith, Fooks, Collin, Weishaar, & Gilmore, 2010; Ståhl, 2010).

My own experience with the practice of undertaking (Field, et al., 2009), evaluating (Blackwell, Macmillan, & Tenbensel T (in press), 2011) and peer reviewing (Ball, Ward, Thornley, & Quigley, 2009; Macmillan, 2010) HIAs in transport and urban planning
closely reflects the concerns found in the literature. In New Zealand, we have found that HIAs tend to occur too late in the decision-making process to make a difference and are carried out over time frames too brief to achieve meaningful community involvement. Furthermore, the very high level template for assessments (Public Health Advisory Committee, 2005) guides practitioners through a process of “screening, scoping, appraisal and evaluation”, but provides very little methodological basis for evidence based predictions of the direction and magnitude of outcomes. The results of HIAs of transport policies have been recently reviewed (Ball, et al., 2009), finding that they made very little difference to transport policies but did succeed in improving the relationship between health professionals and transport decision-makers, at least for a short period of time.

These emerging critical reflections on HIA have mirrored similar critiques about Environmental Impact Assessment (Jay, Jones, Slinn, & Wood, 2007; Morgan, 1998). Analysts of both these tools have begun to recognise the need for methods that integrate qualitative and quantitative information using more participatory approaches (Fitzpatrick & Sinclair, 2003), as well as modelling methods that can manage interdependencies (Morgan, 1998).

4.2. Comparative risk assessment

In an attempt to address the difficulties with integrating the range of health and environmental effects of transport policies identified in the HIA literature, Kjellstrom, van Kerkhoff, Bammer and McMichael (2003) have recommended the use of comparative risk assessment (CRA), a systematic analysis of the effects of changing exposure to risks on a range of health outcomes that is useful for aggregate regional or national analyses (Ezzati, 2000). An important part of CRA is the conversion of all effects into Disability Adjusted Life Years (DALYs) to allow a systematic comparison between outcomes accounting for mortality, morbidity and demographics as demonstrated in the Global Burden of Disease (Lopez, 2005). Without being associated with a health impact assessment, Woodcock, et al.(2009) used this method in a research exercise to compare the health effects of alternative transport policies for London and Delhi. The project used spreadsheet models to project DALYs for road traffic injury, air pollution and physical activity to 2030 using two time points for four different scenarios (business-as-usual, low-emission vehicles, more active travel, and a combination of the two interventions). This study was the first to quantify the comparative co-benefits of
transport policies to mitigate climate change, but did not model the effects of specific policies. This limitation, as well as the lack of involvement of transport policy stakeholders meant the influence of the results on transport policy has been limited. Nevertheless, similar integrated assessments have proliferated very recently, including attempts to quantify the public health benefits of specific policies such as a bike sharing scheme (Rojas-Rueda, De Nazelle, Tainio, & Nieuwenhuijsen, 2011), and theoretical mode shifts to more cycling (de Hartog, et al., 2010; Lindsay, Macmillan, & Woodward, 2011) or reduced car use (Grabow, et al., 2011).

4.3. Participatory policy, planning and research processes

Participatory action research (PAR) has emerged as an applied social science that attempts to address criticisms of the “professional expert” model of research and technocratic policy-making (Fischer, 1993; Whyte, 1989). Unlike more deductive forms of public health research, PAR takes a pragmatic approach, seeking to effect change as a response to understanding the circumstances of health. Participatory action research attempts to ensure joint enquiry between participants and researchers to empower people to take action on the social and structural determinants of health on a local or regional scale (Baum, MacDougall, & Smith, 2006; de Koning & Martin, 1996). There is therefore a greater emphasis on the relationship between researcher and researched, with action and empowerment discussions focusing on the control of research questions, methods and academic institutions, as well as the co-production and ownership of knowledge (Lantz, Israel, Schulz, & Reyes, 2006). A fundamental principle of PAR approaches is to make the role of power imbalance explicit, with the objective of creating more equal power relationships (Lantz, et al., 2006). In an approach that echoes cyclical policy making, PAR aims for a cyclical approach to research, reflection and action (Cornwall, 1996) that draws on the work of Paulo Freire (2000).

In a parallel development, since the 1960s community participation has been acknowledged as fundamental to successful urban planning (Davidoff, 1965; Fainstein & Fainstein, 1972; Peattie, 1968). Arnstein (1969) published her seminal paper about participation and power in an era of urban citizen protest. She introduced a hierarchy of participation ranging from blatant manipulation of communities by authorities, to “citizen control” of decision-making. The emergence of participatory action research has led to calls for a greater emphasis on participatory policy making in the general public policy
literature more recently (deLeon, 1998a, 1998b; Fischer, 1993, 1998; Weimer, 1998), as the limitations of our current forms of representative democracy are recognised (Magnette, 2003; J. Newman, Barnes, Sullivan, & Knops, 2004). While PAR emphasises the relationship between researcher and researched, participatory policy approaches shift the focus to the relationship between citizens and policy-makers (Fischer, 1993). Genuine participatory approaches to urban planning and transport policy have been recognised as important for achieving the changes required for wellbeing and sustainability, by increasing understanding of the requirements for equity to be achieved, as well as by fostering joint learning and ultimately greater acceptance and support for planning policies (Fischer, 1993, 1998; Healey, 1998; Sanchez & Wolf, 2005). Furthermore, when participation leads to community capacity-building and transport policies that reflect this empowerment, participation in policy-making can be a wellbeing end as well as a means (Adaman & Devine, 2001; Laverack, 2007). Arnstein’s ladder of citizen participation (1969) demonstrated clearly that much of the activity labelled as participation by policy makers is either not empowering, or actively harmful.

Despite the participatory discourse in research and policy making, urban and transport planning has been conceptualised as complex (Booth & Richardson, 2001) and has been dominated by rationalist, top-down, technocratic processes (Bickerstaff, Tolley, & Walker, 2002; Brugge, Leong, & Lai, 1999). As a result of this dominance, transport and urban planning policy-makers are likely to have little experience in participatory approaches to policy that are successful in community capacity-building (Sanchez & Wolf, 2005). Environmental sustainability in urban planning has been identified as one example of a policy issue that lacks “publics”, or groups with an active interest (Burby, 2003). This lack of active participation is often followed by latent opposition to implementation. Despite these challenges, a recent review of citizen participation in urban planning in the US (Burby, 2003) concluded that where there was broad stakeholder involvement in the development of plans, this significantly strengthened public health objectives and increased their likelihood of successful implementation.

Published reports of participatory transport policy processes that have achieved a measure of success in changing planning direction have concentrated on neighbourhood level transport issues and projects (Booth & Richardson, 2001; Brugge, et al., 1999; Innes & Booher, 2004; J. Newman, et al., 2004). Experiences with regional level policy processes reveal more difficulty with identifying and including the opinions of community
stakeholders (Burby, 2003), even when more innovative strategies such as online deliberation are used (Lowry, 2010). Lessons from the UK suggest that a significant power shift from centralised governance to local boards has led to successful influence of communities on specific local level projects. However, the capacity of current participatory methods has been limited for lay people’s engagement in debates about regional level issues, and involvement continues to be limited to post-hoc consultation (Booth & Richardson, 2001; J. Newman, et al., 2004).

More recent analyses of the role of participation argue for a more nuanced understanding and approach to citizen participation in policy making (K. Collins & Ison, 2006). A linear hierarchical approach to participation that focuses only on empowerment ignores a more complex set of roles and responsibilities on the part of both individuals and authorities that require different approaches to participation at different times and in different contexts (Titter & McCallum, 2006; Wilcox, 1994). These experiences with participation point towards the need for collective facilitated processes of group or social learning with wider purposes than empowerment alone (K. Collins & Ison, 2006).

For example, Wilcox suggests five levels of participation which offer increasing control to a range of stakeholders, and which are all appropriate in different planning circumstances (Wilcox, 1994):

1. Provision of information
2. Offering a number of options and listening to feedback
3. Deciding together
4. Acting together
5. Supporting independent community initiatives

These more recent analyses also make some recommendations for techniques to improve the process and outcomes of participation in policy making (as opposed to local plan making). Techniques are required that achieve collective learning (Laird, 1993); are able to incorporate both quantifiable and non-quantifiable variables in the context of a complex system (Healey, 2006); be flexible enough to include a variety of actors in different phases of policy development and decision-making (Wilcox, 1994); test evidence against the range of options available (Laird, 1993); and address uncertainty and conflict between stakeholders (Dietz & Stern, 1998; Wilcox, 1994). These requirements address the contribution of knowledge and understanding to meaningful participation, but
these techniques need to be accompanied by real influence on policy decisions (Laird, 1993)

The next sections demonstrate how system dynamics modelling (a broadly integrative scientific tool) can be extended to be transdisciplinary, addressing some of the challenges that have arisen from experience with both Health Impact Assessment and participatory policy making.

### 4.4. System dynamics modelling

System dynamics (SD) modelling is a relatively recent method, having been developed from an initial understanding of the structure and behaviour of corporations (“industrial dynamics”) in the 1950s by Jay Forrester (1961). Forrester combined major systems thought across engineering, economics, the self-regulation theories of cybernetics, and his experience with industrial management (Richardson, 1991b), to develop some generalisable theories about the processes of decision-making in industry. Firstly he recognised that decisions were based on relatively simple mental models with hidden underlying assumptions. He theorised that the human mind performs poorly at estimating the dynamic consequences of feedback and interaction between different parts of the a system, so that even when consensus-based decisions are made, these decisions often lead to unintended and unexpected consequences. Having recognised that complex industrial management systems were governed by structural feedback loops and behaved in counterintuitive ways in response to corrective policies, Forrester (1971a) quickly expanded his theoretical approach to other complex systems. The concept of structure determining dynamic behaviour was seen to be applicable to any social, ecological or engineering system where interacting feedback loops govern behaviour, causing sensible intuitive decision-making to fail. The fundamental underlying theoretical assumptions of SD modelling described by Forrester can be summarised as follows (Forrester, 1969, 1980; Sterman, 2000, 2006):

1. A complex system is a high-order, nonlinear, multiple loop feedback structure
2. The behaviour of a complex system is governed by its structure
3. Reinforcing (positive) and balancing (negative) feedback loops comprise the structure
4. The structure is also characterised by the accumulation of “stocks” that could include people, information, material resources or even abstract or metaphysical states.

5. Time delays between cause and effect are a consequence of these structural features and are manifested in tensions between the short-term and long-term effects of policies.

Richardson (2011) has recently emphasised a sixth fundamental principle from Forrester’s work, that of endogeneity. The dynamic behaviour of a feedback system is a result of its internal structure rather than exogenous influences.

Two of Forrester’s earliest SD models addressed issues of urban governance and global sustainability. In *Urban Dynamics* (1969), Forrester developed an aggregated model of an urban area to enhance understanding of the feedback processes governing urban economic growth and stagnation that was seen to be a major problematic feature of American cities. This city-level model included feedback sectors relating to workforce and housing markets, business, enterprise and industry, taxation and population change. This model allowed a much more explicit debate about the failed attempts to address urban economic stagnation, and suggested improved policy choices.

At the same time, the Club of Rome\(^{12}\) was converging multidisciplinary concern regarding international economic approaches to resource consumption in an increasingly globalised world. Building on Forrester’s work on issues of global economic and population growth in the context of limited resources (1971b), the Club of Rome’s first report, *Limits to Growth* (Meadows, Meadows, Randers, & Behrens III, 1972), used Forrester’s earlier SD modelling to address questions of whether global policies were leading to a sustainable future, and what options there were for moving smoothly from a pattern of growth to a sustainable equilibrium. This initial use of SD modelling to address questions of global sustainability has continued, not only with updates to the original *Limits to Growth* report (Meadows, Meadows, & Randers, 1992; Meadows, Randers, & Meadows, 2004), but also with other modelling efforts, for example to understand climate change (Dhakal & Shrestha; Sawin, et al., 2009), water systems (Stave, 2003) and energy policy (Naill, 1992).

The early SD models are instructive, demonstrating how underlying values shape the way a problem is conceptualised, and showing that a model developed by one or two people will be heavily influenced by their underlying values. In *Urban Dynamics* the urban decay and stagnation was framed as a problem of economics, and it was the economic consequences that were of interest to the authors. The tentative recommendations were therefore narrowly focused on reaching a goal of economic balance in a city, ignoring the social, wellbeing and environmental consequences of that balance. Published two years later, *World Dynamics* demonstrated that a more transdisciplinary approach to the creation of an SD model can encapsulate a range of desired outcomes that include environmental, social and economic equilibriums at a global level, and that these goals can be aligned through an integrated SD modelling approach. These early experiences demonstrated that SD modelling could be useful for meeting some of the previously identified principles for decision-making, in particular those relating to the need for integrating knowledge from different disciplines and understanding complex systems. However, they also highlight the need for approaches to SD that question the values shaping research questions, and allow for wider participation. This is discussed further in Section 4.5.

**4.4.1. SD modelling compared with other dynamic approaches**

The above discussion has demonstrated the potential usefulness of SD modelling for participatory policy-making. However, there is a second relevant modelling method that is able to demonstrate change dynamically over time and incorporate non-linearity and feedback. Agent-Based Modelling (ABM) has begun to be used for purposes similar to SD modelling, including for considering transport policy. While SD modelling assumes that aggregate system trends are a result of the underlying structure of a system, ABM represents an alternative dynamic systems modelling paradigm (Lorenz, 2009; Schieritz & Milling, 2003), by assuming that the behaviour we see in a system is an emergent property of the aggregated choices and interactions between many individual autonomous actors within it (Macy & Willer, 2002). Schieritz and Milling (2003) contrast this with SD modelling as “modelling the trees” compared with “modelling the forest”. Modelling using ABM involves setting up rules that govern the behaviour and interactions of agents and then simulating the results of interactions and choices over time (Epstein, 1999). Its emergence from sociology means that ABM tends to be used to model social networks and favours the idea that evident trends are a result of social rules rather than system
structures (Macy & Willer, 2002). Although ABM agents are “people-like” (Zhang & Levinson, 2004), its use in transport research for traffic and travel demand management has demonstrated that agents can be a variety of aspects of a transport system such as cars, routes or destinations (Schleiffer, 2002).

The hypotheses that have emerged from the literature review of commuting and wellbeing suggest that while the behaviour of individuals and their interactions do influence the system level trends, increasing stakeholder understanding of the causal structure of the system is likely to be important for achieving policy change. ABM is not designed to elucidate this, while SD modelling seems unique in its ability to do this in a collaborative process (Meadows, 1997; Saeed, 2003). Below I describe further the use of SD modelling in transport, public health and participatory decision-making.

### 4.4.2. SD modelling and public health

In addition to its continued use in understanding environmental and global sustainability dynamics, the use of SD modelling in health research is a growing field. SD modelling has been applied to a wide range of health research questions in recent years. In addition to a number of clinical and health delivery questions (Lane, Monefeldt, & Husemann, 2003; Lattimer, et al., 2004; B. Walker & Haslett, 2001), there has been increasing interest in the use of simulation models for public health questions since the 1970s (Homer & Hirsch, 2006). These have included modelling of the capacity of healthcare systems to deal with chronic diseases (Homer, et al., 2004; Luginbuhl, Forsyth, Hirsch, & Goodman, 1981); infectious disease epidemiology (Atun, Lebcir, Drobniewski, & Coker, 2005); the epidemiology and prevention of substance abuse (Holder & Blose, 1987); and the interaction between diet and physical activity in obesity (Abdel-Hamid, 2003).

In 2006, the *American Journal of Public Health* devoted an issue to systems thinking and modelling in public health practice. It was identified in this series of papers that public health issues such as the rise of drug-resistant infectious diseases, increasing health system budgets, ethnic and socioeconomic health disparities and growing obesity all met the definitions of complex system problems, and were both persistent and resistant to attempted policy solutions (Homer & Hirsch, 2006).

At the broadest level, Milstein, Homer and Hirsch (2010) have recently developed an interactive model to allow policy-makers to explore the effects of national health reforms,
including expanding health insurance coverage, increasing healthcare quality, enabling healthier behaviours and building safer environments in the US.

Diabetes is a particular area where SD modelling has been used to garner insights for public health policy. A model of population flows in diabetes has been developed for the US Centers for Disease Control and Prevention (A. P. Jones, et al., 2006) to explore implications of different control and prevention strategies. A range of policy options were simulated, including enhanced clinical diabetes management, improving the management of pre-diabetes, and a suite of policies to reduce the prevalence of obesity. These simulations led to policy insights, for example that improving clinical management alone would lead to an increase in diabetes prevalence compared with business as usual, negating the benefits of management efforts; and that very long delays should be expected between implementation of policies to reduce obesity and diabetes outcomes. The model was also used to critique the US national target to reduce diabetes prevalence by 38% by 2010 (Milstein, et al., 2007), identifying that this goal was impossible to achieve given the factors affecting incidence, diagnosis and mortality. The modelling has allowed more realistic targets to be set in keeping with plausible trajectories for risk factors and interventions. Building on this work, the same group has developed a national-level prevention model for all chronic disease (Homer, Hirsch, & Milstein, 2007). This has resulted in recommendations to shift the balance of investment towards more upstream prevention of risk factors and to reform the health insurance economy.

4.4.3. SD and transport modelling

The past decade has seen the development of a number of comprehensive transport SD models in response to limitations in traditional transport policy-making methods for meeting the goals of sustainable transportation identified in the 1990s and described in Section 3.1. These models fall into two categories: those that simulate regional transport systems and allow experimentation of the effects of a number of policy options on a range of outcomes (such as the models described by Pfaffenbichler, Emberger, & Shepherd, 2008; Raux, 2003; Schade, Martino, & Roda, 1999; Swanson & Steer Davies Gleave, 2008); and those that are specifically designed to test a single policy, or address a specific outcome (such as those described by BenDor & Ford, 2006; Han & Hayashi, 2008). Very few of these models have been described in the peer reviewed literature, and those
summarised below have been identified from a search of the grey literature, including reference lists of review articles and internet searches.

The ASTRA project (Rothengatter & Schade, 2000; Schade, et al., 1999) adopted a system dynamics approach to assessing the impacts of the European Union’s Common Transport Policy. The model included four sectors to assess these impacts – a transport system sector to model infrastructure and traffic volumes; a regional economic and land use sector to show the interaction between housing, business and transport; a macroeconomic sector including national and European economic influences on transport mode; and an environmental sector to demonstrate the impacts of population, trip numbers and transport mode on injuries, air pollution and noise.

Raux (2003) describes a more specific model dealing with the relative attractiveness of car and public transport modes in an urban setting. The regulation of public transport financing, including the relationship between public transport demand, fares and subsidies comprises one major sector of this model. A second sector is a mode-share model between car and public transport use for urban trips that is based on comparative price and time costs for the two modes. The published material indicates that it was only developed to demonstrate the potential of SD modelling for urban trip simulation rather than having been fully developed, validated and simulated.

More recently, both the Integrated Dynamic Land Use and Transport Model MARS (Pfaffenbichler, et al., 2008) and the Urban Dynamic Model UDM (Swanson & Steer Davies Gleave, 2008) have integrated land use and transport aspects into a single SD model. The UDM is explicitly an extension of Forrester’s original Urban Dynamics model, connecting land use and transport policies to assess their impacts on the attractiveness of localities for businesses and households. The outcomes modelled in the UDM are related to employment levels and regional economic growth. On the other hand, MARS is designed to assess the influences of both transport and land use policy instruments on housing development and location, employment location and transport mode choice. Outcomes include economic costs, air pollution and accidents. UDM includes feedback loops describing the relative attractiveness of the car compared with public transport for commuting, based on financial and time costs. The model has been used to assist in transport decision-making in the UK, Europe and Asia.
The transport SD models described have been developed by transport modelling specialists in a technocratic process. They have therefore been limited in their understanding of the social and health influences and outcomes of transport behaviours. In particular, financial and time cost influences on mode share incorporated in these models have assumed a relatively homogeneous level of mode choice across population groups. Furthermore, health and environmental outcomes are modelled as exogenous outcomes, whereas many of the health outcomes are likely to be involved in feedback loops influencing people’s transport behaviour.

4.5. Participatory SD modelling

Donella Meadows (1972), a founding system dynamicist, realised early on the potential for SD modelling as a powerful tool to improve democratic decision-making for sustainability at a range of geographical scales, from the local to the global. Since then modellers involved in large scale environmental management issues have recognised that integrated models for environmental sustainability require input from a wide range of stakeholders using group modelling processes to build a shared understanding about the way complex systems work (Costanza & Ruth, 1998; Videira, Antunes, & Santos, 2009). Two overlapping approaches to participatory SD modelling have been developed (Videira, Antunes, & Santos, 2005) and these are described below.

Van den Belt, Deutsch and Jansson (1998) first described a “mediated modelling” technique applying workshop-based computer simulation modelling to the management of a coastal zone in 1998. The emphasis in this approach is to incorporate data into a simulation model during discussions to enhance consensus about the management of ecosystems, rather than to understand the underlying feedback processes influencing system behaviour.

A growing number of case studies using mediated modelling have since been reported. In Mediated Modeling (van den Belt, 2004) five case studies are described using mediated modelling to build consensus about watershed management (Peterson, Kenimer, & Grant, 2004; van den Belt, Wenger, & Harris, 2004), coastal zone management (Videira, van den Belt, Antunes, Santunos, & Gamito, 2004), and national park and wildlife management (Cornwell, 2004; Pedersen & Grant, 2004). The case studies varied in their stakeholder input. Participants included local government policy agents, scientists, commercial and
industrial representatives, community members and members of NGOs\textsuperscript{13}. Mediated modelling followed a three-step process in the cases described: establishing a stakeholder group and developing a preliminary model; undertaking a series of workshops to develop a simulation model and run scenarios; and disseminating the model with evaluation of the process. The processes described took between four and twelve months (although a more recently reported mediated modelling exercise spanned 5 years (van den Belt, et al., 2006)). The models developed were all reported as “scoping” models, representing a starting point for further discussion, investigation and model development. Although preliminary recommendations could be made in some of the case studies, most of the cases were more useful for identifying data gaps and research questions for further investigation. Despite this, building and using SD models enabled improved understanding across sectors and allowed stakeholders to explore multiple policy options for achieving beneficial results.

A second group of participatory SD modelling efforts has built on organizational “group model building” with corporate clients in the fields of operations research (Richardson & Andersen, 1995; Vennix, 1992), and in public policy (Vennix, 1996). These emphasize the development of a qualitative understanding of the system as well as developing a quantitative simulation model. Although this approach has mainly been translated into the management of natural ecosystems (Videira, et al., 2009), it has also featured in urban decision-making. Two such examples come from the United States, where participatory SD modelling has been used to improve public involvement in decisions about transport-related air pollution (Stave, 2002) and water management (Stave, 2003) in Las Vegas.

The group model building exercise to improve public involvement in transport-related air quality management (Stave, 2002) involved elected officials, representatives of businesses, community residents, environmental activists and public transport users in monthly workshops over the period of a year. This advisory group was developed by the regional transport committee, which instigated the modelling project. Between five and eight members of the group were involved in constructing the model, which included both a qualitative causal diagram describing feedback loops, and a simulation model demonstrating a range of policy outcomes. The causal diagram described the relationships between carbon monoxide generation and a number of subsectors including population

\textsuperscript{13} Non-Governmental Organisations
growth, attractiveness of different transport modes, road construction, congestion and personal vehicle use. The simulation model allowed the regional transport committee to simulate the outcomes of a range of policy options for congestion, air quality and cost. Insights from the model allowed the committee to recommend a US$2.5 billion package of policy options balancing costs with desired air pollution outcomes.

Participatory SD modelling is an emerging tool for public policy decision-making, and little has been published evaluating its effectiveness, although a review of 107 case studies using group model building to address problems within profit, governmental and not-for-profit organisations (Rouwette, Vennix, & van Mullekom, 2002) provides some insight into characteristics of effective group model building processes. Measurable improvements in understanding by participants is common, and these improvements are enhanced by participants becoming familiar with the underlying structure of the model by participation in its construction rather than merely experimenting with a simulation interface. Approximately one half of the case studies that were focused on finding solutions reported system improvements from the modelling process. However, the review identified a lack of reporting of outcomes among the case studies. The authors also found that the development of a quantitative simulation model was more likely to lead to system changes than the use of a qualitative model alone. Stave (2002) describes other critical factors for success in her transport modelling study. In particular, the commitment of the regional transport commission’s general manager and the transport agency’s technical staff meant that the project was championed within the policy-making agency. The involvement of a small number of “highly-respected” community representatives was also seen as important for success.

The reported experience with participatory SD modelling to date endorses it as a method for meeting the principles outlined previously for sustainability decision-making, particularly by enabling transdisciplinary approaches to understanding complex systems. In addition, the method has the potential to address some of the limitations outlined in critiques of both health impact assessment and participatory policy making endeavours, in particular by its ability to integrate qualitative and quantitative knowledge and create a more level power structure for learning about a system and evaluating policy options.

There are some characteristics of the most successful experiences with participatory modelling that are likely to make its use more difficult for regional level urban transport
decision-making. In particular, the most successful case studies that achieved long-lasting transdisciplinary participation have focused on localities where residents and other stakeholders were likely to have a strong sense of “place”, providing commitment to take part in what appears to be a time intensive process. Finding a broadly representative group of stakeholders with a sense of commitment to regional level policies may be challenging.

In contrast to the positivist origins of SD modelling, which emerged out of engineering theory (rather than systems thinking) (Richardson, 1991a), participatory SD modelling is similar to the development of a grounded theory that is constructivist in nature (Charmaz, 2005), in that the process involves the development of an integrated collection of concepts and the description of relationships between concepts in an iterative process (Glaser, 1992), synthesising a useful more generalised theory from the data of individuals (Charmaz, 2005). In this sense it is both constructivist and fits with pragmatic ideas of usefulness for achieving change. In other words, the purpose of a participatory SD modelling process can be considered to be:

“to come up with good ideas worth implementing, that can be implemented, and to have the needed coalition of support necessary for implementation...ensuring that what gets decided...as a result of our facilitation has the group’s highest confidence that it is going to work out well over time.” (Eden, et al., 2008)

Van den Belt (2004, p. 53) considers mediated modelling to be action research, but unlike the description of PAR provided in Section 4.3 which emphasise the empowerment of participants, she focuses on the role of the modeller in taking action through advocacy, dissemination and facilitating authentic group learning.

These theoretical developments mean participatory system dynamics aligns closely with my own position in relation to the thesis questions. This can be summarised from Chapter 2 as a socio-ecological and emancipatory understanding of public health, coupled with a pragmatic methodological approach that involves negotiating multiple truths to discover workable solutions to a problem.
4.6. Summary

In this chapter I have described Health Impact Assessment, Comparative Risk Assessment and Participatory Action Research as the currently accepted methods for improving the incorporation of wellbeing into non-health policy-making. In doing so, I have identified the limitations of these methods in understanding complex systems such as urban transport. This chapter reviews the use of SD modelling as a broadly integrative approach, particularly demonstrating its usefulness in understanding issues of public health, environmental sustainability and transport separately. I have argued that SD modelling allows for an integrated understanding of the implications of transport policy decisions on commuting behaviour, wellbeing and sustainability.

In addition, reported experiences to date suggest that a participatory approach to SD modelling may be a methodological step towards the transdisciplinary co-production of knowledge required for healthy and sustainable transport policy, identified by Wilcox as “deciding together” (Section 4.3). Furthermore, experiences with SD modelling have demonstrated that it can be successfully used at a range of geographic scales, from the local to the global.

The characteristics of the problem at hand (that of improving the wellbeing outcomes of transport policy in relation to the trip to work) that make it particularly amenable to a participatory SD modelling approach include:

1. The transport system is complex, and stakeholders are unable to consider the effects of policy-choices on wellbeing and sustainability using the disparate information available
2. The literature review suggests that the behaviour of the system is influenced more heavily by policy and physical structures than the choices of autonomous agents
3. The outcomes of policy interventions are likely to be characterised by unintended consequences, and unexpected delays in policy responses
4. Understanding the feedback loops in the system requires a combination of qualitative work to conceptualise a shared understanding of the system, and quantitative data about changes and outcomes
5. The participation of a wide range of stakeholders will be required to increase the chances of successful policy implementation
The following chapters describe the design and outcomes of an SD modelling process, using both qualitative causal loop identification and simulation modelling to explore the outcomes of transport policy choices on public health outcomes. In the next chapter I describe how I have applied the experiences with participatory modelling to date to the design of the study, keeping in mind the potential challenges identified in these experiences.
Chapter 5. Methods

The participatory SD modelling studies described in the previous chapter (Section 4.5) were used to inform the design of an SD modelling process to understand the dynamics of commuting and public health in Auckland, as well as identify the policies that are most likely to be effective for changing commuting patterns for public health. The modelling study was undertaken between 2008 and 2011.

The generic SD modelling heuristic guide described by Saeed (Saeed, 1992) was used to design the steps in the process. The guide consists of following five steps:

1. Defining desired outcomes
2. Describing the behaviour of problems related to the outcomes over time using existing data and stakeholder mental models
3. Representing these mental models in computer modelling software and exploring model behaviour in comparison with historical trends over time
4. Validation of model representation through comparison and revision
5. Dynamic model simulation, conclusions and recommendations

These steps are represented in Figure 5-1, which also demonstrates the iterative nature of the process. Combining group model building methods described by Richardson, Anderson and Vennix (Richardson & Andersen, 1995; Vennix, 1992; Vennix, Andersen, & Richardson, 1997), as well as the participatory SD methods described by van den Belt and her colleagues (2004; 2006; 1998; 2004) and Stave (2002, 2003), I describe the study process for qualitative and simulation model development in detail in this chapter. The process involved three overlapping phases: a preparation phase to define the problem and model scope, identify stakeholders, conduct preliminary individual interviews with stakeholders and develop a preliminary model; a modelling phase involving the development of conceptual and simulation models; and a follow-up phase to review the simulation model, undertake policy simulations, make recommendations and allow participants the opportunity to take ownership of the model, so that they can use it to influence policy.
At the outset the research was planned as an application of participatory SD within the context of workplace travel planning in a specific location, East Tamaki. However the outcome of the systematic review of workplace travel plans described above led to a change in focus for the study. It became an application of SD in the context of regional transport policy. The overarching aim of the research remained unchanged – to contribute to the transformation of transport policy by identifying effective policy levers to increase the use of sustainable travel modes in the trip to work, thereby improving health, equity and environmental outcomes. This change had implications for the design and implementation of study methods. Discussions of model building processes particularly stress the need for a flexible and evolving process that uses a variety of techniques to support knowledge elicitation, exploration and evaluating options. The
study’s change in scale from locality-based to regional also required some accommodation in the methods applied.

In designing the process I was also aware of some important differences between SD experiences in environmental management and the use of participatory SD to address a regional urban policy problem. Many ecological feedback loops are well understood, with indicators (such as water quality or tree cover) easy to measure with established field techniques. Land ownership and a sense of place in localities such as a watershed provide people with a strong sense of ownership, connection and therefore a “stake” in policy decisions. In contrast, developing a regional urban transport policy, with decisions to be made at both a national and local level, has few of these features. There was therefore some uncertainty about how participation of a wide range of stakeholders in an SD process could be achieved for regional transport policy in Auckland.

This chapter therefore not only describes the methods as originally planned, but also reflects the review and refinement that occurred during the implementation of the study.

5.1. Objectives of the participatory SD study

In undertaking an SD modelling study there were some specific questions I wished to answer that would contribute to the wider aim of the thesis which is to influence transport policy for healthy commuting.

1. How do a broad range of stakeholders understand the links between the trip to work and a broad definition of public health and do these understandings match the literature?
2. Can we integrate knowledge about commuting, health and sustainability into a set of feedback loops that represent a consensus understanding?
3. Is it possible to undertake this integration using participatory methods?
4. Can a simulation model be developed that assists with improving the public health outcomes of commuting by influencing transport policy?

The hypotheses underlying these questions were as follows:

1. Integrating the complex links between commuting and health, equity and sustainability into policy-making can improve the public health outcomes of policies
2. Using methods that enhance the understanding of a wide range of stakeholders can lead to stronger policies that are more likely to be successfully implemented with support from communities.

3. SD modelling can potentially be useful for undertaking the kind of participatory knowledge integration needed to achieve health and sustainability goals by changing the trip to work.

5.2. SD modelling concepts, language and software

The theoretical principles of SD modelling were described previously (Section 4.4) and this section describes further the language, structural and software foundations for developing an SD model, summarised from Richardson (2001, pp. 807-810) and Sterman (2000, pp. 107-122; 2006). Mathematically, a simulation SD model is a set of connected first-order differential and integral equations, which are either discrete or continuous. To create the dynamic simulation time is divided into very small discrete intervals (dt) and the system is stepped through these.

Feedback thinking combined with the concepts of levels (stocks) and rates (flows) are at the heart of SD modelling.

5.2.1. Feedback structure determines behaviour

A major underlying principle of SD modelling is that there are only a limited number of basic patterns of dynamic behaviour, and systems exhibit these patterns over time either simply or in combination. The three basic patterns of behaviour are exponential growth (including exponential collapse, and linear change over time), goal-seeking behaviour, and oscillation (Sterman, 2000, p. 108). A fourth very common pattern of behaviour seen in complex systems is s-shaped growth, which is a combination of exponential growth followed by goal-seeking. These patterns of behaviour are demonstrated graphically in Figure 5-2.
These simple patterns of behaviour are created by archetypal underlying feedback loop structures, described below (Sterman, 2000, pp. 108-122).

1. **Exponential growth (or collapse)**

The feedback structure creating exponential growth or collapse is one of positive feedback, demonstrated in the generic causal loop diagram below (Figure 5-3). Arrows indicate the direction of causal inferences, and signs at the arrow heads (- or +) indicate the polarity of the relationship. A positive sign indicates that an increase in the causal variable results in an increase in the dependent variable, and a decrease leads to a decrease in the dependent variable. A negative sign indicates that a change in the causal variable leads to a change in the opposite direction for the dependent variable.
The circle in the centre of the loop identifies that the loop is self-reinforcing, creating positive feedback (denoted by an R). If the net rate of increase is negative, then collapse rather than growth will ensue.

2. **Goal-seeking**

Gradual approach to a desired state is created by negative feedback loops acting to bring the state of a system gradually towards a desired state, by comparing the current state with a goal. All these cycles have the same generic structure shown in Figure 5-4. As the state of the system approaches the desired state, the discrepancy reduces and the size of corrective action also gets smaller.

![Figure 5-4 Goal-seeking structure](image)

The circle in the centre of the loop identifies the loop as a negative feedback, or Balancing loop (B). Every negative loop includes a process to compare the state of the system with either an explicit or implicit goal, and take corrective action. Many policy interventions involve balancing loops aimed at correcting perceived system problems.

3. **Oscillation**

Oscillations are also caused by negative feedback or balancing loops. However, in an oscillating system the pattern is of continuing over-shoot followed by under-shoot of the goal. This is caused by different kinds of delays in the system leading to the corrective action continuing beyond the goal, and leading to a corrective action in the opposite direction. Stable, unstable and damped oscillations are possible, and each has an
archetypal structure associated with it, but always with a central delayed balancing loop (Figure 5-5).

The delays in the causal loop diagram are denoted by two parallel lines through the arrows, and take a number of different forms. There may be delays in the measurement and reporting of the state of the system, delays in decision-making and taking action once the discrepancy has been identified, or delays inherent in the system’s response to those actions once taken.

5.2.2. Stock and flow language

The accumulation of variables as stocks acts as the “memory” of the state of the system at any point in time, while flows define the rate of accumulation or depletion of stocks. In SD diagrams these stocks and flows are depicted by the symbols shown in Figure 5-6.
The concepts of stocks and flows are very similar to the epidemiological concepts of prevalence (a stock) and incidence (a flow). Flows can be determined by other stocks, or by other variables, known as “converters”. These converters serve many functions in an SD model. They define and calculate algebraic relationships, act as a repository for constants, hold graphical functions that define relationships between variables, or define external model inputs. The diagram below demonstrates a stock and flow diagram of population growth, showing some likely converters. Converters and converters, stocks and flows, and converters and flows can all be linked by connectors – arrows which allow information to flow from one variable to another (Figure 5-6). The following model diagram for population growth provides a simple demonstration of these elements (Figure 5-7).

The stock of population in Figure 5-7 is determined by three flows: an inward flow of births; an outward flow of deaths; and a bi-flow combining inward and outward migration. These flows are determined by fertility, mortality and migration rates. Population levels also determine the number of births and deaths per time period.
5.2.3. SD modelling software

There are two main SD modelling software programmes available for academic researchers: Vensim PLE\textsuperscript{14} and STELLA\textsuperscript{15}. Each has strengths for depicting causal loop diagrams, developing simulation models and communicating the structure of models and the results of simulations. I have used Vensim for developing the causal loop diagrams and STELLA for the simulation modelling tasks.

5.3. Defining the problem and model boundary

Historical trend data, the international and national literature, and the documented concerns of decision-makers were used to describe the “problematic” trend in commuting patterns over time, as well as projected future trends. These trends were used to construct a reference mode, defined as a graphical representation of a pattern of behaviour conceptualised from related evidence, over a time span appropriate for addressing the trends (Albin, 1997; Saeed, 1999; Sterman, 2000, p. 90). Although using quantitative historical trends, this exercise is qualitative since it involves representing a pattern, and projecting this pattern into an inferred future (Saeed, 1999).

The Auckland metropolitan region was used as the study base for three main reasons. Firstly, the Auckland region is the largest metropolitan area in the country, the home of one quarter of the total New Zealand population (approximately 1.5 million people). Secondly, Auckland is acknowledged to be a sprawling and car-dependent region. Traffic congestion and poor public transport feature highest in residents’ identification of issues detracting from quality of life in the region (Mein Consulting Ltd, 2008). Finally, the region is the geographical scale for local government transport planning in New Zealand.

5.4. Identification of stakeholders

Over a period of approximately 12 months during 2008 I used a purposive sampling strategy to identify major stakeholders involved in designing or implementing transport policy. Groups who might be affected by transport policy were also approached, particularly those groups identified by the literature as likely to incur health inequities.

\textsuperscript{14} The academic version of the Ventana Simulation Environment, version 5.8b, Ventana Systems, Inc., copyright © 1988-2008
\textsuperscript{15} The academic version of the isee systems modelling environment, versions 9.1.0 to 9.1.4 from isee systems, inc., copyright © 1985-2010
because of transport policy. An *a priori* determination of the major stakeholder groups that were considered to be important to represent was undertaken. The sampling frame for the recruitment of stakeholders is summarised in Box 5-1.

<table>
<thead>
<tr>
<th>Policy makers</th>
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<tbody>
<tr>
<td>Māori community organisations</td>
</tr>
<tr>
<td>Pacific community organisations</td>
</tr>
<tr>
<td>People with disabilities</td>
</tr>
<tr>
<td>Low income families</td>
</tr>
<tr>
<td>Youth</td>
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<tr>
<td>Businesses and employees</td>
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<tr>
<td>Local government</td>
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<tr>
<td>Public health</td>
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<td>Academics</td>
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</tbody>
</table>

*Box 5-1 Sampling frame for general recruitment of stakeholders*

An important issue identified in the review of participatory modelling (Section 4.5) was one of geographical scale. The most successful participatory modelling processes were those that focused on a particular place with which stakeholders had a strong connection. In contrast, the urban transport policy example included only a very small number of wider community representatives. The lack of grassroots community engagement exemplified in this study is reflected in Auckland experiences of community consultation on previous draft regional transport strategies. Although affected communities, Māori and the general public are invited to make submissions on draft regional land transport strategies, these consultations tend to have a low response rate from a non-representative sample of the population (Mein Consulting Ltd, 2008).

To address this issue an initial stakeholder group was chosen that would elicit local place-based themes about commuting and public health to understand the underlying feedback loop structure. This was followed by a shift in the balance of involvement towards more regional stakeholders. Participants at both the regional and local scale were involved during the development of the qualitative part of the study, while only regional stakeholders were involved in the simulation modelling.

There are differences in the emphasis placed on simulation and qualitative work among the examples of participatory modelling in the literature. In considering these differences
Beall and Ford (Beall & Ford, 2010; Ford, 2010) identify two main approaches, which give greater weight either to qualitative model formulation or to the quantitative simulation, and which they term “simulate at the end” or “simulate early and often”. The way the process was formulated for this study reflects the first approach, to emphasise the development of the qualitative aspects of the model and the development of feedback loops before making a transition to the development of a simulation model. This approach is illustrated in Figure 5-1 below.

Identifying both regional and local stakeholder involved initially approaching widely divergent groups using the *a priori* determination. Initial discussions about the project with these groups were followed by a snowball sampling approach where the groups were able to recommend appropriate representatives of their own group, or recommend other groups. Starting with a very diverse set of initial informants meant that the risk of
capturing a biased subset of potentially important participants was minimised. It was important that participants had a mandate from the group they represented to speak on behalf of the group during the study and were adept at two-way information sharing through the process, which involved stakeholders reporting information from the modelling process to their represented groups and returning with feedback to contribute to the further development of the model.

The identification of regional policy stakeholders began with the Auckland Regional Transport Committee. Regional councils are required under the Land Transport Management Act 2003 (LTMA) to establish regional transport committees, and the LTMA also prescribes membership representation to these committees. Under the LTMA, regional transport committees are required to include representatives of the regional council, each local council in the region, and the national transport agency. In addition, the committee must include a “cultural” representative and a member to represent each objective in the national transport strategy (economic development, safety and personal security, public health, access and mobility, and environmental sustainability). At the time stakeholders were approached, the Auckland Regional Transport Committee included greater representation than was stipulated under the LTMA, as summarised in Table 5-1.

<table>
<thead>
<tr>
<th>Representation</th>
<th>Number of Members</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional Councillors</td>
<td>6</td>
</tr>
<tr>
<td>Local Councillors</td>
<td>7 (one for each local council)</td>
</tr>
<tr>
<td>Land Transport New Zealand (national transport agency)</td>
<td>1</td>
</tr>
<tr>
<td>Cultural representative</td>
<td>1 (Māori representative)</td>
</tr>
<tr>
<td>Economic development</td>
<td>2</td>
</tr>
<tr>
<td>Safety and personal security</td>
<td>1</td>
</tr>
<tr>
<td>Public health</td>
<td>1</td>
</tr>
<tr>
<td>Access and mobility</td>
<td>3</td>
</tr>
<tr>
<td>Environmental Sustainability</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5-1 Auckland Regional Land Transport Committee Membership 2008

The Auckland Regional Transport Committee prepares the regional land transport strategy, which establishes regional transport objectives, outcomes and targets. The
Committee is supported by a Technical Advisory Committee that includes transport representatives from all the region’s local councils, and other technical experts including a representative of the regional public health service. At the time of stakeholder identification, a separate Auckland Regional Transport Authority (ARTA) was responsible for preparing the regional transport programme, which lists and prioritises transport projects.

The Auckland Regional Transport Committee, the Technical Advisory Committee and ARTA were all invited to provide representation to the project. It became clear from a review of the Auckland Regional Transport Committee membership that some *a priori* stakeholders of interest were under-represented at the regional level. These included Māori and Pacific communities, women with school children and low income householders. These groups were therefore further targeted.

Local narratives that reflected the challenges of commuting in the Auckland Region, particularly for low income families, were drawn from employers and employees in East Tamaki. These narratives addressed some of the representation gaps identified within the Auckland Regional Transport Committee. East Tamaki was identified as the fastest growing employment centre in the Auckland Region, with poor access to public transport, and a very high level of car dependence – over 90% of employees travelled by car, truck or van in the 2006 census, and 78% of employees were the sole occupant driver of a vehicle in the trip to work (Figure 5-9). Businesses and industries in East Tamaki draw employees from a labour force that lives predominantly in local suburbs, including areas of high socioeconomic deprivation (my own analysis of 2006 census data).

Stakeholder participation in workshops was fluid over the period of the project, allowing for new members to be identified, and members to move in and out of the project as it evolved from the conceptual phase to the simulation phase. The groups identified in the sampling frame were maintained through the qualitative phase. However, involvement of stakeholders changed significantly during the transition to simulation modelling.
Figure 5-9 Commuting mode share for people working in East Tamaki compared with regional mode share (Statistics New Zealand, 2006a)
Over the period of the participatory modelling process the political landscape in the Auckland Region changed dramatically. As the process moved from qualitative modelling to simulation modelling in 2010, a new governance structure for the region was defined and legislated by central government, unifying five local councils and the Auckland Regional Council into one body, the Auckland Council. The structures for transport planning also changed with the demise of the regional council owned Auckland Regional Transport Authority, and the formation of a Council Controlled Organisation charged with the implementation of transport policy in the region. This resulted in a significant period of stakeholder uncertainty and council staff turnover during the project. A further period of relationship development with the new unified Auckland Council and new regional policy stakeholders was undertaken as the new governance structures were formed.

5.4.1. Stakeholder group size

There is very little guidance in the literature regarding the optimal size for mediated modelling participant groups, although there is some agreement that the size of the group needs to balance a number of competing needs. On one hand, it is important to have a group large enough to accommodate representatives across stakeholder organisations (horizontal integration), and at a range of hierarchical levels (vertical integration) (Stead, 2010), as well as develop a substantial organisational platform supporting policy change (Rouwette & Vennix, 2006; Vennix, 1996, p. 111). On the other hand, larger groups have been found to perform less effectively, require more formalised discussion processes (Vennix, 1992), inhibit collaboration and reduce opportunities for some individuals to contribute (Rouwette & Vennix, 2006; van den Belt, 2004). Groups of between 5 and 40 have been used and recommended (Richardson & Andersen, 1995; Stave, 2002; van den Belt, 2004). Vennix (1996) argues that although small groups (of about 5) lead to greater satisfaction of participants, the type and structure of tasks is more important than the size of the group in determining group performance. For this study the aim was to develop a participant group including approximately 20 members, with between ten and 15 members likely to attend each workshop.
5.5. Māori Steering Group

Maintaining robust and representative indigenous participation was central to the study. In particular, I sought to uphold the principles of the Treaty of Waitangi, address issues of Māori health inequity potentially exacerbated by transport policy, understand the particular links between commuting and wellbeing for tangata whenua (first people of the land), and privilege indigenous voices that were recognised as missing from the transport policy process. Identification of appropriate Māori stakeholders to take part in the workshops began regionally with the Māori representative on the Auckland Regional Land Transport Committee, and locally with the tangata whenua of East Tamaki. As discussions proceeded, Māori stakeholders recommended the establishment of a Māori steering group for the study as a way of providing guidance to the process, supporting the individual Māori representatives who would be attending the workshops as part of the study, and protecting the collective ownership of Māori knowledge (L. T. Smith, 2005).

Over the 12-month period of general stakeholder recruitment, the members of a Māori steering group were therefore also recruited, using a similar process of networking with an a priori sampling frame. This included representatives of tangata whenua of East Tamaki, regional representatives of other iwi (tribes) residing in Auckland and urban Māori with lost connections to their ancestry. Members of the Māori Steering Group were in positions of leadership with a mandate to provide guidance to the study about the impacts of transport policy and transport patterns on Māori wellbeing. The Steering Group met six times at regular intervals over the study period (between October 2008 and September 2010). The group was able to provide local and regional perspectives, advice on tikanga (appropriate cultural process) and valuable critical debate about the appropriateness of the methods for representing Māori concepts and world views.

The negotiation and maintenance of collaborative relationships became a journey in cross-cultural collaborative research that built on the following principles (Bishop & Glynn, 1999; Gibbs, 2001):

1. Extensive and ongoing establishment and maintenance of relationships with a long term view, recognising the Māori Steering Group as a “whānau (family) of interest”, with hierarchically determined positions, decided by the group
2. Participatory research practices within relationships categorised by connectedness, engagement and a “participatory consciousness”
3. “Somatic” engagement in the research collaboration that was physical, ethical and moral
4. Relinquishing control over how Māori knowledge was used and disseminated in the study
5. Sharing of knowledge generated by the research in ways that were beneficial to Māori participants

Bishop & Glynn (1999) also discusses the importance of treating research ideas as *koha*, or offerings where the right of acceptance and participation is left open; the centrality of the notion of the *waka* (used by Bishop to mean the ancestral, tribal canoe) as a metaphor for fostering consensus; and the significance of *kawa* (protocol) as a metaphor for correctness of research process.

The Terms of Reference for the Māori Steering Group (see Appendix A), the identification of roles and the conduct of meetings were developed to reflect these principles.

### 5.6. Individual interviews

Individual face-to-face interviews were undertaken with each participating stakeholder. The purpose of these interviews was to co-construct a preliminary understanding of each participant’s mental model about the relationships between transport patterns and behaviours, and wellbeing outcomes for individuals and communities. Understanding the participants’ construction of cause and effect in terms of transport behaviour was an important aspect of this.

The interviews were approached as an active process, a collaborative effort resulting in a negotiated understanding, in keeping with arguments about qualitative interviewing as a non-neutral exchange (Fontana & Frey, 2005; Scheurich, 1995). As the interviewer, I engaged in conversations that included some careful sharing of experiences where those experiences overlapped, which created a context of shared understanding and assisted with gaining the trust of participants (Fontana & Frey, 2005). In preparing for the interviews I reflected on my own understanding of the links between transport and wellbeing, including reflecting on what I considered the main influences on my own transport behaviours, and the behaviours of others. As the interviews progressed I
continued to reflect on how my assessment of the issues changed over time, as well as critically reflecting on the range of rapport achieved with the diverse participants.

Interviews were semi-structured and conducted in a location chosen by the participant. As I introduced the study, went through the Participant Information Sheet and discussed what the study would involve, I also explained the nature of action research, in terms of iterative knowledge generation and advocacy (on the part of the researcher but also providing knowledge resources for participants to act), emphasising that this would be at a regional level rather than relating directly to the participant’s neighbourhood or locality.

All interviews began with a single standardised question:

“Can you tell me a bit about your views on the links between commuting (how people get to work) and the wellbeing of your community?”

Since the purpose of the interviews was to co-construct an understanding of the relationships between variables, in preparation for the development of a conceptual SD model, interviews were not transcribed. Instead, during each interview a process of visual mapping took place. Both the researcher and the participant had a pencil and eraser, and were involved in the co-construction of a “cognitive map” (Eden, 1988; Eden & Ackermann, 2004). Cognitive mapping is one technique for exploring mental processes (Kitchen & Spickett-Jones, 2003), particularly when the relationships between causes and consequences are of interest, as well as the consideration of opposing choices or behaviours (Eden, 1988). Furthermore, they have been identified as a useful starting point for collating and comparing the views of a number of stakeholders in relation to a policy issue (Eden & Ackermann, 2004). A cognitive map comprises concepts linked by arrows demonstrating polarity to form a chain of underlying causes and consequences.

To develop the cognitive maps with participants, a number of further questions were asked prompted by emerging themes in the interview:

“Let’s talk a bit more about the causes of this – why/how does this happen?”

“Let’s talk a bit more about the consequences of this – what happens because of this?”

During each interview, themes and links continued to be elicited, explored and mapped until the participant had no further themes to discuss. Throughout each interview, themes and their maps were reviewed and revised through further discussion. At the end of each
interview, all the cognitive maps were reviewed, to ensure that the interview had been accurately recorded.

Following each interview, reviewed and reorganised the cognitive maps to create maps which followed a trajectory from assumptions or assertions about the way things work, through actions and strategies that result from those assertions, to outputs, outcomes or consequences. These revised maps were then entered into Decision Explorer® (Banxia Software) which formalises the maps, identifies variables and clusters, and ranks highly linked concepts.

During the interviewing phase, I developed a set of cognitive maps reflecting my own mental model, as well as my understanding of the literature. This was explicitly included as part of the preliminary analysis of the problem and the development of the qualitative feedback loops.

Formalised cognitive maps were sent back to participants who had the opportunity to review their maps and make changes. Opportunities were provided for both face-to-face meetings to review the maps, as well as telephone meetings.

5.7. Development of the qualitative feedback loops

Following the formalisation of all cognitive maps, a full list of variables identified in the interviews was developed. Some preliminary consolidation was undertaken to create a manageable number of variables, eliminating repetition and combining variables with a similar meaning. Two workshops were then undertaken over the next 12 months to develop the qualitative feedback loops.

The first workshop included three structured activities. The first activity was a review and discussion of the formalised cognitive maps, where participants were given the opportunity to introduce themselves to the group, talk about the organisations and groups they represented, and reflect on the cognitive mapping process and outcomes. New ideas and relationships that arose from this activity were recorded. The second activity was a silent clustering activity. Variables identified from the cognitive maps were placed randomly on a wall, and participants were asked to silently cluster the variables by moving them around. At the end of this silent clustering, participants undertook a third activity to name the clusters or themes, and to link the themes to each other.
Following the first workshop the themes identified were used to develop a set of preliminary feedback loops using Vensim PLE®. The clustering exercises and the cognitive maps were reviewed in detail to elicit relationships between variables, and feedback loops. Where conflicting relationships were identified from the cognitive maps, and from the discussions in the first workshop, these were reflected in the preliminary feedback loops. The loops were also informed by evidence from the literature, where evidence existed for the relationships and themes being modelled. The main stock was also identified for each theme. In moving from the linear relationships identified by the interviews and the literature to causal loop diagrams, I used the SD principles described in Section 5.2, which describe the feedback structures underlying particular patterns of behaviour over time.

The second workshop included two planned activities. The first part of the workshop was spent introducing participants who had not attended the previous workshop and reviewing the themes agreed upon in the first workshop. Participants were then introduced to the basic principles of SD modelling, particularly stocks, flows and feedback loops, using examples of feedback loops and a simple simulation model. Reasons for using system dynamics were reviewed, and we discussed ideas about the questions the model was being designed to address. During the first part of this workshop it was also important to discuss the use of language in the model.

The second part of the workshop was organised around a review of the preliminary feedback loops. Participants were divided into small groups and rotated at intervals among the groups to discuss the feedback loops. A facilitator was placed with each group to assist with the continuity of the conversation, interpretation of the feedback loops, and ensuring that participants were recording their comments and changes. As well as reviewing the feedback loops, participants were asked to consider the reference modes for the main stock in each feedback loop. A sketch graph was provided for each stock that illustrated how the stock had changed over time. Participants were asked to discuss the shape of the graph over time, and to sketch the reference mode that represented their “hopes” (how they would like to see the stock change in the future with good policy intervention) and “fears” (the direction they were concerned the stock would take in the future with no intervention). A number of policy insights also naturally followed from the discussions about the feedback loops during the workshop. These were also recorded and added to a narrative to accompany each feedback loop.
Following the second workshop, the three facilitators met to go over the discussions and comments from the workshop, including the comments on the feedback loops and the reference mode sketches. This information was used to refine and simplify the feedback loops, identify differences of opinion about what variables meant, how they were named and the relationships between them. These differences were reflected in the feedback loops. The feedback loops were then combined to form a single working version of the qualitative model. A presentation was developed including the separate feedback loops in their themes and a synthesis of the entire model to demonstrate that the separate loops were interconnected.

The presentation and the working version of the model were then used in a series of meetings and smaller workshops with the organisations represented by participants. Participants were invited to set up meetings and workshops with decision-makers and other members of their organisations, and were also invited to take part in the presentation and discussions. The model was also presented to the Regional Transport Committee, the Regional Urban Design and Transport Committee, and groups represented by participants in the Māori Steering Group. Discussions and comments from these small workshops, meetings and presentations contributed to further refinement of the qualitative model and the consequent policy insights.

5.8. Development of the simulation model

Development of the qualitative feedback loops resulted in a conceptual model with a large number of sectors. To simulate all sectors was beyond the scope of the thesis. Furthermore, the sectors ranged widely in their ease of simulation, with some sectors being more likely to have data available to allow them to be simulated with validity. Other sectors posed many theoretical questions for further empirical research. A decision was therefore needed about where to focus the simulation efforts for this study, acknowledging that some sectors would follow quite easily from the development of the central model structure, and others would remain as qualitative sectors with important policy insights. This decision was guided by a scoping workshop held with the study co-investigators to re-visit the model boundaries and direction and consider which sectors were most likely to have available data. It was decided that the feedback loops relating to cycling injury and cycling mode share would be a useful starting point. The decision to
direct the simulation modelling effort to these feedback loops also directed discussions with further regional stakeholders involved in cycling policy.

The simulation model was developed using STELLA® software, as this was found to have superior features for communicating models to stakeholders.

5.8.1. Identification and incorporation of data

The feedback loops identified for cycling in the qualitative work were used to develop a list of time-series and parameter data requirements the sector to be simulated. The identification of data and development of the model equations were then undertaken by the author in consultation with a small group of individual regional stakeholders within the new Auckland Council and with co-researchers.

Routinely collected data specific to the Auckland Region was used to populate the model where possible. Datasets included regional subsets of national census and survey data and Auckland-specific travel surveys. Survey data about transport preferences was combined with the qualitative data from the interviews and workshops to quantify relationships between factors that influence transport mode behaviour in the trip to work, and the resulting commuting mode shares. The best evidence for estimates of relationships between parameters for wellbeing outcomes was identified from reviews of the published literature. Data and relationships emerging from studies and surveys specific to commuting were used where possible. Where no data were available for commuting, broader transport data were sought. Where no data were available, stakeholder expertise was sought to enable me to make explicit assumptions about effect sizes and dose responses. To enable the simulation of a range of transport mode shifts, dose response curves were developed. Although reviews of the literature often report single risk estimates, dose-response relationships are only rarely available. Assumptions about the size of effects and the shape of dose-response curves were tested against historical trends in important stocks, including trends in the relationships between changing transport mode share and health outcomes.

5.9. Assessing model validity

The philosophical underpinnings of SD modelling, and participatory SD modelling especially, are relativist, constructivist and holistic (Barlas, 1996; Sterman, 2000, p. 89).
This has led to considerations of robustness that are in keeping with these philosophical approaches. The expanding discussions about validity in the SD literature consistently argue that establishing the validity of an SD model is a continuous process of building confidence in the model, which has two dimensions. These can be described as usefulness and structural validity (Barlas, 1996; Ford, 2010, pp. 162-167; Forrester & Senge, 1980; Schwaninger & Grösser, 2008; Sterman, 2000, pp. 845-891; van den Belt, 2004, pp. 93-95; Vennix, 1996). The first dimension relates to the applicability and successful implementation of the model for its purpose, which can be assessed by evaluating both the modelling process and the policy changes that ensue from the model’s use. The usefulness of a model depends on aspects such as importance, clarity, the balance between parsimony and comprehensiveness, and fruitfulness and practicality (Schwaninger & Grösser, 2008). Particular questions that can be asked about the usefulness of the model include whether the important parameters that are thought to influence the behaviour of the model over time are endogenous in the model’s causal loop structure (Sterman, 2000, p. 852); and whether the modelling process helped change the system for the better by increasing stakeholder insight into the system structure and effective policy levers (Sterman, 2000, p. 861; van den Belt, 2004, p. 93).

The second dimension relates to the model’s internal validity, and can incorporate a number of more formal validity procedures to assess the validity of the model structure, followed by procedures to consider how well the simulation outputs fit with historical time series data and other sources of information (Barlas, 1996). Barlas (1996) groups formal validity procedures into direct analysis of the structure of the model through comparison with knowledge about the real system structure; structure-oriented behaviour tests involving extreme-condition testing of model-generated behaviours; and tests of model simulation behaviour patterns against time series data. A summary of specific procedures relating to these three types of formal model validation is provided below (Table 5-2). Sterman (2000, pp. 855-858) also emphasises the importance of ensuring modelling efforts are replicable, through the thorough documentation of structure and data sources.

The model purpose is also relevant when considering what aspects of formal validity testing are most useful. An SD model that is designed for advancing understanding into patterns of behaviour rather than point prediction is reflective in nature, and Sterman argues that validity testing should therefore focus on uncovering and discussing structural
flaws and assumptions, rather than on fitting model-generated behaviours to historical time-series data.

In this study we expected that reliable data for the simulation model would be sparse, particularly dose-response data from high quality epidemiological studies. The testing of the model was therefore weighted towards the structural, with parameter behaviour patterns tested for plausibility. Extensive parameter and structure confirmation was undertaken during the construction of the simulation model and is described in the next chapters. Parameter estimation was achieved using routinely collected data for the Auckland region, and the quality and relevance of dose-response data was considered before being incorporated into the model. Thorough recording of data sources and levels of uncertainty was undertaken to maximise the replicability of the study.

<table>
<thead>
<tr>
<th>Formal validation</th>
<th>Specific procedures</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direct structure validity</strong></td>
<td>Parameter confirmation</td>
<td>Consistency with elements of the real system</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Numerical accuracy of constants</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Parameters chosen from best evidence</td>
</tr>
<tr>
<td></td>
<td>Structure confirmation</td>
<td>Equations reflect real relationships, conforming to physical laws</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Relationships based on best evidence</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extreme conditions testing of relationships</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dimensional consistency testing</td>
</tr>
<tr>
<td><strong>Structure-oriented behaviour</strong></td>
<td>Extreme-condition procedures</td>
<td>Plausible behaviour with extreme values</td>
</tr>
<tr>
<td></td>
<td>Behaviour sensitivity procedures</td>
<td>Identification of parameters to which the model is highly sensitive</td>
</tr>
<tr>
<td><strong>Behaviour pattern validity</strong></td>
<td>Pattern consistency for transient behaviours</td>
<td>Graphical and visual comparisons with historical time series data</td>
</tr>
<tr>
<td></td>
<td>Pattern consistency for steady-state behaviours</td>
<td>Trend, period, average and variation comparisons using statistical methods</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phase lag testing</td>
</tr>
</tbody>
</table>

Table 5-2 Summary of formal validation procedures, adapted from Forrester and Senge (1980), Barlas (1996), Sterman (2000, pp. 861-888) and van den Belt (2004, pp. 93-94)

Sources of data varied widely, and the assessment of data quality and uncertainty was multi-dimensional. The usual consideration of quality in epidemiological study designs
(ranging from randomised controlled trials with dose-response relationships to ecological studies and convenience sample surveys) was one dimension. Others included the relevance of the data to commuting and to the Auckland population, as well as the quality and completeness of routinely collected administrative data (such as cycling injuries).

Extreme-condition and dimensional testing was undertaken for equations, and the stability of model-generated behaviours to extreme parameter values was also tested. Sensitivity testing of model-generated behaviours to different parameters and relationships was considered to have a dual purpose in this study: firstly, to maximise the accuracy of those parameters, and secondly to identify significant questions for further research. The behaviours of interest in this study were changing commuting patterns, which were considered to be transient rather than steady-state behaviours. Once confidence in the structural aspects of the model had been achieved, visual and graphical procedures were used to compare model-generated behaviours with historical time series data. These led to revisions of both model structure, as well as the shape of dose-response curves.

5.10. Policy simulations

The commuter cycling simulation model was used to test a range of policies to increase commuter cycling. Their effectiveness was tested against a baseline “business-as-usual scenario”. Policies were chosen based on existing plans for cycling in the Auckland region and from the best evidence for effectiveness of interventions in the literature. Quantified targets likely to be most relevant and affected by policies to increase commuter cycling were identified from the ARLTS. As described in Section 3.2.3 the 2010-2040 strategy has a range of targets for 2040 related to its objectives. The policy simulations were used to test each policy for comparative effectiveness at reaching these targets, as well as the direction, shape and magnitude of change in other public health outcomes over time.

The simulation model and the policy simulations were then presented to policy stakeholders within the new unified Auckland Council and NZTA.
5.11. Roles in the SD modelling process

Experienced participatory SD modellers have identified a number of specific roles needing explicit attention for a successful group model building process. Five separate roles have been identified (Richardson & Andersen, 1995), some of which can be overlapping functions performed by a single person (van den Belt, 2004). The facilitator elicits knowledge and manages the group process during workshops; the modeller formulates the SD model both during and between workshops, reflecting knowledge elicited through the interviews, workshops and other meetings; a process coach concentrates on the dynamics between participants during the workshops, identifying issues with relationships and noting how the participants contribute and work together; and a recorder makes notes about the workshop proceedings to assist the modelling efforts. A gatekeeper role has also been identified as important. This is a person who acts as the champion and advocate within the sponsoring organisation.

The fulfilment of these five roles is depicted graphically in Figure 5-10. All five of these identified functions were present in this study; however the gatekeeper role was least active. The first four roles were distributed among three people: the author (AM), David Rees (DR), an experienced SD modeller, and Karen Witten (KW), who assisted with the workshops. Although the Auckland Regional Council could be considered as the
sponsoring organisation, as it was responsible for transport policy making, they were not funding the study and the policy representatives participating in the study did not fulfil roles as gatekeepers. This role was partially filled by the candidate while working as a public health representative in the development of regional transport policy.

5.12. Ethics

Ethics approval for the study was granted in September 2007 by the University of Auckland Human Participants Ethics Committee, for three years. This was extended in September 2010 for a further three years, to allow for a continuing process of participatory modelling and action. All participants gave written consent to be part of the project, having had the opportunity to consider the participant information sheet and discuss what was involved. Participating stakeholders and members of the Māori Steering Group were reimbursed for attending workshops and meetings. Copies of the consent forms and information sheets for the project are provided in Appendix B. In addition to the requirements of the University Ethics Committee, specific attention was paid to ethical requirements for undertaking collaborative research with Māori participants and organisations, in keeping with the underlying values of the research. In particular, I considered the guidance of L. T. Smith (2005), Cram (2001), and Hudson and Russell (2009) in developing and undertaking relationships with Māori stakeholders in both the participant group and the Māori Steering Group. L. T. Smith (2005) identifies some particular ethical issues that were considered. Individual informed consent in the context of wider community approval and collective support for individual participation were both considered as requirements to maintain a collective protection of indigenous knowledge. Other ethical aspects of collaborative research with Māori that were considered are summarised in Table 5-3, as well as the shaping of the research in response. Hudson and Russell (2009) frame these principles around revised Treaty of Waitangi principles, and I have grouped the summary using this framework.
Chapter 5 - Methods

<table>
<thead>
<tr>
<th>Ethical principle</th>
<th>How the principle was addressed in the study</th>
</tr>
</thead>
</table>
| Aroha ki te tangata – Respect for people | Building a longer term research partnership with Māori organisations  
Respect for cultural knowledge  
Individual consent placed in the context of community approval  
Face-to-face meetings  
Listening carefully before speaking  
Appropriate meeting spaces chosen by Māori stakeholders |
| Mana whakahaere – Control and participation | Collective construction of knowledge  
Control of Māori participants and steering group over use of knowledge and concepts in the research  
Reflecting about the research process, and aligning of the research goals with Māori goals for wellbeing |
| Manaaki ki te tangata – Reciprocity | A combination of hosting and being hosted was used during the study  
Knowledge sharing in ways that were useful to stakeholders  
Attempting to ensure benefits were realised by Māori stakeholders |

Table 5-3 Framework used for ethical conduct in engaging with Māori, adapted from L. T. Smith (1999, 2005), Cram (2001), Hudson and Russell (2009)

5.13. Summary

In this chapter I described the specific methods used to develop an SD model of commuting and public health, based on a generalised heuristic process. I incorporated lessons from participatory environmental modelling and experiences in transport and air pollution SD modelling from the United States. These lessons have been used to develop a process that was contextually appropriate to the transport and socio-cultural systems in the Auckland region. The methods described in the chapter also reflect changes to the planned methods throughout the modelling process, highlighting the need for flexibility in implementing SD processes that are responsive to the changing political context.

The next three chapters describe the results of the SD modelling process. These cover the three phases described in the introduction to this chapter (preparation, modelling and follow-up), although I report on preparation and the development of the qualitative model in a single chapter, followed by the development of the cycling simulation model. A third chapter describes the selection of policies and the results of the policy simulation.
Chapter 6. Development of the qualitative SD model

The next three chapters describe the results of the SD modelling process described in Chapter 5. In this chapter I report on the preparation phase of the process and the development of a conceptual SD model, which involved defining the problem through the construction of an overarching reference mode; identifying and recruiting a wide range of stakeholders; completing interviews with participants; analysing cognitive maps; and developing qualitative feedback loops through a series of workshops and meetings. This part of the process culminated in the conceptual representation of the system’s structure and behaviour as a set of causal loop diagrams.

During the process of eliciting participants’ cognitive maps to develop the conceptual model, I undertook a parallel process of mapping my own understanding of the links between commuting and public health, informed by the literature review.

6.1. Problem Definition

Commuting in the Auckland region, defined as trips to and from work, has become increasingly reliant on private motor vehicles (cars, vans and motor cycles), with gradual declines in the share of other modes of transport, including public transport, walking and cycling. This growth in private vehicle dependence has resulted in the complex effects on social, physical, environmental and economic wellbeing described in Chapter 2. The trend has been highlighted as a significant regional problem by policy makers, academics and communities. For example, policy makers have identified the escalating cost of providing road infrastructure to cope with the expected growth in demand, growing vulnerability to oil prices, problems of congestion and the contribution of short vehicle trips to climate change (Auckland Regional Council, 2005, 2010a; Auckland Regional Transport Authority, 2007). Furthermore, residents of the region consistently rate traffic, congestion and poor public transport as the most significant issues detracting from quality of life (Auckland Council, 2011; Mein Consulting Ltd, 2008).

Since 1971, each New Zealand Census has included a question about the one main means of travel to work (MMTW question, the 2006 version is given in Figure 6-1). Although this underestimates walking and cycling as part of longer trips that include other modes,
the census trip to work question represents the most complete national data set for monitoring commuting trends over time.

Figure 6-1 2006 Census trip to work question (Statistics New Zealand, 2006b, Chapter 11))

The numbers of people using the four main modes of transport for commuting over time and the changes in mode share are shown in Figure 6-2. Both graphs are derived from census data since 1991 for the Auckland region. The graphs demonstrate that the growth in motor vehicle use for commuting is not only a response to population growth, but also represents a growth in mode share. Concurrently the sharpest decline has been seen in the proportion of people cycling over time.

In both graphs, light vehicle commuting includes driving or travelling as a passenger in a private or company car, van or light truck. Public transport includes bus and train travel, and walking also includes jogging or running to work. I have calculated mode shares as the proportion of total commuters, excluding those who worked from home or did not go to work on census day.
Figure 6-2 Trends in numbers of commuters and mode share for the main modes of travel to work by census year 1996-2006, in four aggregated categories (candidate’s own analysis of Census data16)

Figure 6-3 depicts the reference mode for the problem described above. This is a graphical depiction that demonstrates past as well as projected future trends. It includes expected business-as-usual trends, as well as those indicated strategically as desired by policy makers. I have used a time horizon of 40 years, projecting trends to 2050. This was

16 This work is based on Statistics New Zealand’s data from the Census of Population and Dwellings, licensed by Statistics New Zealand for re-use under the Creative Commons Attribution-Non-commercial 3.0 New Zealand license, provided March 2008
considered a sufficient time for policy decisions to be implemented and have an effect on projected trends.

The predicted pattern of behaviour for car commuting in the reference mode is S-shaped growth as described in Section 5.2.1 (exponential growth followed eventually by goal seeking behaviour). This pattern of growth suggests one or more initially dominant reinforcing loops (in the exponential growth phase), followed by the dominance of one or more balancing loops (in the goal-seeking phase). The gap between the desired and expected patterns of growth in car commuting suggests that a “business-as-usual” approach will not achieve desired outcomes.
6.2. Interview and workshop participants

Sixteen individual participants were interviewed and six others took part in the stakeholder workshops and meetings. They represented a wide range of overlapping stakeholder groups in accordance with the *a priori* sampling frame described in Section 5.4. Many of the organisations represented had a local focus on East Tamaki, while others were more regional representatives. The organisations represented are summarised in Table 6-1. Participants often represented more than one stakeholder group; therefore the total number of participants in Table 6-1 does not reflect the number of participants involved in the study workshops. Fifteen of the 22 participants were women, five identified as Māori and three as Pacific. Ages of participants ranged from 17 to over 65 years. None of the participants had experience with SD modelling, although the two transport policy analysts were familiar with transport modelling.

<table>
<thead>
<tr>
<th>Groups represented</th>
<th>Participants representing each group</th>
</tr>
</thead>
<tbody>
<tr>
<td>People with disabilities</td>
<td>1</td>
</tr>
<tr>
<td>Māori communities</td>
<td>5</td>
</tr>
<tr>
<td>Pacific communities</td>
<td>3</td>
</tr>
<tr>
<td>Low income families</td>
<td>3</td>
</tr>
<tr>
<td>Young people</td>
<td>2</td>
</tr>
<tr>
<td>Regional transport policy makers</td>
<td>2</td>
</tr>
<tr>
<td>National transport agency</td>
<td>1</td>
</tr>
<tr>
<td>Public health</td>
<td>2</td>
</tr>
<tr>
<td>Local business association</td>
<td>1</td>
</tr>
<tr>
<td>Local tertiary institution</td>
<td>2</td>
</tr>
<tr>
<td>Local government</td>
<td>2</td>
</tr>
<tr>
<td>Regional government</td>
<td>2</td>
</tr>
<tr>
<td>Academics</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 6-1 Groups represented in the interviews and workshops to develop the qualitative model

A further 15 representatives of regional and local Māori organisations comprised the Māori Steering Group which met six times over the duration of the project. All these representatives self-identified as Māori. *Iwi* and organisations represented on this group were wide ranging, as shown in Box 6-1.
Chapter 6 – Development of the qualitative model

<table>
<thead>
<tr>
<th>Box 6-1 Regional and local organisations represented on the Māori Steering Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tangata whenua (Tainui Iwi)</td>
</tr>
<tr>
<td>Manukau City Council Treaty of Waitangi Committee</td>
</tr>
<tr>
<td>Manukau City Council Treaty of Waitangi Unit</td>
</tr>
<tr>
<td>Te Ora o Manukau (Manukau the Healthy City)</td>
</tr>
<tr>
<td>Otara Community Board</td>
</tr>
<tr>
<td>Hapai te Hauora Tapui (Māori regional public health provider)</td>
</tr>
<tr>
<td>Auckland Regional Public Health Service (Māori Health)</td>
</tr>
<tr>
<td>Accident Compensation Corporation</td>
</tr>
<tr>
<td>Māori Injury Prevention Group</td>
</tr>
<tr>
<td>Manukau Urban Māori Authority</td>
</tr>
<tr>
<td>Auckland District Māori Council</td>
</tr>
<tr>
<td>Auckland Disability Law Service</td>
</tr>
<tr>
<td>Te Kupenga Hauora Māori (Māori Health Research Centre, University of Auckland)</td>
</tr>
<tr>
<td>DesignTRIBE Architects</td>
</tr>
<tr>
<td>Auckland Regional Transport Authority</td>
</tr>
</tbody>
</table>

During the development of the qualitative model I sought input through presentations, meetings, discussions and workshops with members of the following organisations, who provided valuable information and feedback as well as representatives at workshops:

- Counties Manukau Disability Steering Group
- New Zealand Transport Agency
- Auckland Regional Council Transport and Urban Design Committee
- Te Ora o Manukau Board
- Manukau City Council Treaty of Waitangi Committee

The roles of the organisations listed in this section are summarised in Appendix C.
6.3. Cognitive mapping interviews

Sixteen semi-structured interviews were undertaken in person during 2008, at a range of venues chosen by participants (including workplaces, participants’ homes and public meeting places). Interviews lasted between one and three hours. In two instances a pair of participants representing similar interests chose to be interviewed together.

Recording was achieved through the shared development of cognitive maps. The predetermined opening questions and the maps in progress determined the direction of the interview. The cognitive maps were reviewed at intervals during the interviews, and revised with further discussion and clarification. A new map was started for each emergent theme or narrative. Although few participants took the opportunity to write or draw on the cognitive maps themselves, all participants actively engaged with the diagrams, directing alterations to words, phrases and arrows, and using the diagrams to elaborate on earlier or new narratives. At the end of each interview, all cognitive maps were reviewed with the participant to ensure there was shared understanding of the meaning of variables, relationships with other variables, and that there were no new narratives to be explored. Between three and eight cognitive maps were developed for each interview.

Two main patterns of interview emerged. In the first, participants began with an overview of all the issues they thought relevant to the relationship between the trip to work and community wellbeing. The participant then worked through this list during the interview, adding further items to the list for later elaboration. In the second pattern participants began in detail on a particular theme or narrative, and this would trigger further themes and discussions. An example of the cognitive maps developed during the interviews is provided below (Figure 6-4).
Figure 6-4 Example of an interview cognitive map
Following each interview, all interview maps were reviewed and transcribed into a standard format that ordered variables and relationships into assertions or assumptions about the current situation; actions or choices; strategies and behaviour patterns; outputs; and outcomes. Maps were then reviewed either in person or by email with participants. This led to further minor revisions. Figure 6-5 is indicative of the standardised cognitive maps. Relationships between perceived causes and effects, or influences and outcomes are denoted by arrows. Many variables are set up as opposing poles, with ellipses used to mean “rather than”, for example “local government empowering... disempowering” is read as “local government empowering rather than disempowering”. An arrow with a plus sign means the root of the arrow has a positive effect on the variable at the head, while a minus sign means the variable at the root of the arrow has a negative effect on the variable at the head. For example, in Figure 6-5, knowing neighbours inhibits crime and injury.

Figure 6-5 Example of a reviewed and standardised cognitive map
Chapter 6 – Development of the qualitative model

Preliminary analysis of the cognitive maps was undertaken using Decision Explorer® cognitive mapping software. This decision support software generated a complete list of variables and allowed an initial analysis of the themes generating the greatest number of inter-relationships within each interview.

A total of 615 variables were elicited during the interviews. Almost all could be clustered together into 38 relevant preliminary themes. Table 6-2 summarises these themes. The number of variables in each theme reflects the popularity of the theme (how often participants spoke about it) but also the variety of different ways of talking about the theme, such as different words and phrases used with a similar meaning.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Number of variables in theme</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Influences on commuting behaviour</strong></td>
<td></td>
</tr>
<tr>
<td>Local urban design features (zoning, aesthetics, density, transport infrastructure)</td>
<td>71</td>
</tr>
<tr>
<td>Regional urban planning policies and governance</td>
<td>58</td>
</tr>
<tr>
<td>Quality of public transport</td>
<td>52</td>
</tr>
<tr>
<td>Type of employment and organisational facilities and culture</td>
<td>36</td>
</tr>
<tr>
<td>Transport social norms and media stereotypes</td>
<td>27</td>
</tr>
<tr>
<td>Family structures and responsibilities</td>
<td>25</td>
</tr>
<tr>
<td>Fear of crime</td>
<td>24</td>
</tr>
<tr>
<td>Household economics and transport costs</td>
<td>18</td>
</tr>
<tr>
<td>Demographics (gender, age, ethnicity)</td>
<td>9</td>
</tr>
<tr>
<td>Time pressure</td>
<td>8</td>
</tr>
<tr>
<td>Environmental awareness and responsibility</td>
<td>7</td>
</tr>
<tr>
<td>Comparative convenience and reliability</td>
<td>6</td>
</tr>
<tr>
<td>Weather and topography</td>
<td>5</td>
</tr>
<tr>
<td>Fear of injury from other road users</td>
<td>4</td>
</tr>
<tr>
<td>Disability</td>
<td>4</td>
</tr>
<tr>
<td>Having a driver’s licence</td>
<td>3</td>
</tr>
<tr>
<td>Information barriers</td>
<td>2</td>
</tr>
<tr>
<td>Desire for health and fitness</td>
<td>1</td>
</tr>
<tr>
<td>Desire for personal space and privacy</td>
<td>1</td>
</tr>
<tr>
<td><strong>Community wellbeing outcomes</strong></td>
<td></td>
</tr>
<tr>
<td>Mental health, time pressure and stress</td>
<td>46</td>
</tr>
<tr>
<td>Social connection and social wellbeing</td>
<td>45</td>
</tr>
</tbody>
</table>
Structural and policy aspects of the transport system and urban design featured most often as influences on commuting behaviour, while convenience and information were mentioned less often. As a group the participants identified all the connections between commuting and public health discussed in the literature. However, their priorities were more heavily weighted to the effects of current commuting patterns on social and mental wellbeing, particularly the links between commuting, time pressure and stress.

### 6.4. Development of the conceptual model

The workshops and meetings that followed the individual interviews and cognitive mapping analysis occurred over a period of 18 months in 2008 and 2009. The workshops were held during workday evenings, at venues that minimised the cost of attending for community members. A light meal was provided at each workshop, and participants were reimbursed for their time.
The process of participatory modelling was built on previous descriptions used mainly for areas of local ecological significance, and I was testing the viability of such a process in an urban area in New Zealand. By the second workshop it was clear that the level of commitment on the part of stakeholders to a participatory modelling process was low. In particular there was a mismatch in participants’ levels of commitment to regional transport issues and the large amount of time required to take part in a series of workshops. A much more flexible approach was therefore needed to involve stakeholders in discussions about the conceptual model, and much of the model development was undertaken between meetings and workshops rather than by the stakeholders themselves.

6.4.1. Workshop 1

The first three-hour workshop with 12 participants was held in September 2008 at a local tertiary institute. Introductions included what participants hoped would be the result of the research for the groups that were represented. The final versions of the cognitive maps had been provided to the participants, and these formed the basis of an initial discussion of the main issues of car dependence raised in the interviews, and the need for changes to commuting patterns in response to negative public health outcomes identified in the interviews.

Participants then undertook the clustering and theme identification exercise described in Section 5.7. Many of the clusters engendered only brief discussion, with consensus easily reached, while others involved lengthy debate. One of the most debated clusters or themes was about the overlap between Māori values connecting environment and wellbeing (concepts such as kaitiakitanga – guardianship and responsibility for natural resources conferred by ancestral connection to place; waiora – the wellbeing of natural resources such as water and air; and mauriora – life force of nature and spiritual wellbeing) and more widely held connections between environment, culture and wellbeing. This was the beginning of a thread of debate that continued throughout the project. Seventeen themes emerged from the clustering exercise:

1. Safety from injury for cyclists and pedestrians
2. Public transport structures and support
3. Community safety from crime
4. Social connectedness
5. Distance to work
6. Access to services  
7. Equity of access to employment and services  
8. Family commitments, considerations and responsibility  
9. Time budgets and time constraints  
10. Household level economics  
11. The need for buffer time between work and home lives  
12. Workplace support  
13. Local and national planning and governance  
14. The intersection between cultural and environmental wellbeing  
15. Recreational green space and public domain  
16. Physical and mental health impacts  
17. Marketing stereotypes  

These themes, the cognitive maps and the reference mode were all used to construct a series of preliminary causal loop diagrams. The archetypal behaviours described in Section 5.2.1 also guided the formulation of the causal loops.  

Although a wide variety of broad public health outcomes were identified, very few of these outcomes also played a part in influencing commuting behaviour. Most of these outcomes were therefore not part of the causal loops, but rather “externalities” of the dynamic system. Rather than attaching them to particular causal loops, I developed two high level concept diagrams. The first explained the relationship between the causal loops, the reference mode and the various outcomes (Figure 6-6). The second described the outcomes using definitions of wellbeing from the Local Government Act (LGA) and from Māori models of health (Figure 6-7). In developing the concept model and the preliminary causal loops I was mindful of the wide range of terms and concepts used by stakeholders. In keeping with my initial objective to create a consensus model that reflected the input of all stakeholders I used both English and Māori terms and concepts.
Chapter 6 – Development of the qualitative model

Figure 6-6 High level concept diagram used to describe the system
The preliminary set of feedback loops was divided into eight sectors, with multiple postulated causal loops in each sector, and a total of 24 causal loops. These preliminary sectors are described below, and the basis for understanding the causal loops can be found in Section 5.2.1.

**Sector 1: Pedestrian and cyclist injury**

There were six different postulated causal loops in this sector (Figure 6-8), with a central relationship between the level of pedestrian and cyclist injury and the number of people walking and cycling to work, identifying that fear of injury was a strong influence on these modes, particularly for cycling. Conflicting theories were proposed about the relationship between the number of people commuting on foot and by bicycle, and the

17 kaitiakitanga: guardianship responsibility for resources through ancestry, waiora: environmental health, toiora: healthy lifestyles, taha whānau: wellbeing of the family, oranga: participation in society, mana whakahaere: autonomy or sovereignty, mauriora: access to the Māori world
risk of injury. Some stakeholders considered that increasing active commuting would naturally decrease the risk through a “safety in numbers” effect; others considered that there was no such effect. Still others considered that increasing active modes would reduce congestion, allowing car drivers to increase their speeds, and making it more dangerous for walkers and cyclists. Many stakeholders discussed the influence a large number of walkers and cyclists could have on local government investment in infrastructure to improve the safety of these modes. People mentioned specific aspects of investments and regulation including cycling and walking paths, separation of pedestrians and cyclists from cars, maintenance of footpaths and enforcement of speed limits. Physical activity and fitness were identified as important wellbeing outcomes.

![Figure 6-8 Pedestrian and cyclist injury](image)
Sector 2: Public transport infrastructure and services

Stakeholders connected public transport with a range of positive outcomes, including physical activity and social connection, improved air quality and reduced greenhouse gas emissions. Two reinforcing loops were identified (Figure 6-9). The first was a supply and demand loop suggesting that decreasing public transport commuters had led to a lack of investment in public transport, poor quality public transport infrastructure and services, and therefore less public transport commuters (R1). A second consideration was that public transport had become the mode of transport of marginalised groups in society and a lack of wide use by all sectors of society led to vandalism and even poorer quality infrastructure which also deterred commuters (R2).

Many participants argued that the way public transport was currently privatised with weak contractual oversight and a focus on profit had led to declining quality of public transport, as well as services that didn’t meet the needs of the whole community.
Participants specifically mentioned the number of different bus companies, a lack of integration between companies (including integration of tickets), and a focus on profitable routes with a reduction in services not considered profitable.

**Sector 3: Neighbourhood sense of safety from crime**

This sector (Figure 6-10) comprised a single reinforcing loop (R) connecting the number of car commuters at a neighbourhood level with reduced knowledge of neighbours, awareness of community occurrences and activities, reduced participation in neighbourhood relationships and activities, and a heightened sense of distrust about neighbourhood safety. This in turn leads to an increase in fear of walking or cycling in the neighbourhood and an increased likelihood of taking the car to work. Social connection and social wellbeing were identified as the main public health outcomes. The phrase “drive-through neighbourhoods” is used by one participant, who described the situation of many families whose interaction with their street environment was minimised by moving from the house to the garage (sometimes without going outside) and car, travel by car, and return to the garage, all without setting foot in the neighbourhood.
Sector 4: Time, family responsibilities and accessibility of employment, goods and services

Themes 5 to 10 that emerged from the clustering exercise were closely inter-related. An initial set of complex relationships emerged during the analysis, with three main reinforcing feedback loops (Figure 6-11), the first a cycle of car use driven by individual time pressures, creating congestion and further time pressures (R1). Secondly, urban design focused on car use results in sprawl, and increases the distance between households and employment (R2), as well as between households and other goods and services (R3). This encourages further car use and car-focused urban design.

A complex set of mediating factors mean these loops have a gradient of intensity depending on household income (as low income housing tends to be on the periphery of the city); the number of children in the household; the number of parents at home; and culturally mediated family responsibilities. This was seen particularly in relation to Māori and Pacific households, which are more likely to be low income, include more children, include a single-parent and have wider family responsibilities. There was a shared acknowledgement and discussion by many of the stakeholders that inequities could be created by transport and spatial planning and that transport and spatial inequities were likely to exist in Auckland.

The quality and appropriateness of goods and services was emphasised. Stakeholders discussed health promoting aspects of goods and services, such as healthy food choices, as well as the cultural appropriateness of services. In particular participants mentioned the importance of access to Pacific churches, marae, Kura Kaupapa (Māori language schools), and culturally appropriate health services. The need to access these kinds of goods and services as part of the work day was seen to lead to a greater reliance on cars for commuting.

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18 The area in front of a traditional meeting-house and often used to include the whole complex of buildings around this
Sector 5: Workplace support

Workplace support was considered to include the provision of facilities for cyclists; incentives for the use of public transport; removal of incentives for car use such as free parking and company cars; a change of company attitudes; and advocacy to council by business organisations for better infrastructure and services for walking, cycling and public transport.
Journey time predictability was seen as a significant issue for employers, who felt that productivity was harmed by employees not arriving at work on time, particularly for shift work. There was a widely held view that poor public transport services made journey times more unreliable. Five positive feedback loops were considered to be centred on workplace support (Figure 6-12). Greater support by workplaces and business organisations would improve infrastructure and services for non-car modes directly through increasing demand (R1, R2), as well as through advocacy to local government (R5). These would counteract what is currently the dominant loop whereby the car commuting majority of employees is a powerful lobby group for free parking and other car-related perks in the workplace (R3). Furthermore, it was considered that once more employees were using public transport and active modes, businesses would begin to experience financial benefits. These include a reduction in spending on car parks and increased worker productivity resulting from a healthier, happier workforce.
Sector 6: Participation in urban planning and governance

Meaningful participation in urban planning by a diversity of stakeholders was seen to be an important pre-requisite for improving the quality of urban planning, both to achieve equitable provision of services and infrastructure and to reduce the spatial inequities discussed previously. Improvements in spatial equity were considered to result in improved social wellbeing and greater social wellbeing was considered to lead to a more empowered community (R2, R3). It was also thought that if communities could see positive evidence that their participation influenced decisions, especially resulting in improvements to urban infrastructure, this would create a positive feedback loop, with more people willing to participate in planning processes (R1). Better quality urban planning was considered to lead to not just spatial equity but also to urban design to support a range of transport modes. This in turn would reduce car commuting. The link between car commuting and social connection had been made at a neighbourhood level. However, at a city level this link is more tenuous (R4). For many people car commuting also means being able to participate in social groups outside of work that they would not otherwise be able to access.

Figure 6-13 Participation in urban planning and governance
Sector 7: Environmental health and cultural wellbeing for Māori

Several relationships between commuting behaviour and environmental outcomes were identified by participants, including air and water quality and climate change. However, these rarely influenced commuting behaviour. A closer and stronger relationship between obligations of environmental stewardship (kaitiakitanga), environmental health manifested in clean water (waiora), being able to use water resources for traditional purposes, and cultural wellbeing (mauriora) was identified.

A thread of relationships between connections to the Māori world, cultural wellbeing and car commuting was also identified, however these relationships were less clear. The two reinforcing loops identified represented a theoretical connection between car dominance,
environmental degradation, a loss of cultural wellbeing and the replacement of traditional cultures with a “car culture” for young people.

**Sector 8: “Car culture”, marketing stereotypes and social wellbeing**

There was a widely identified connection between the dominance of car use for all trips (including commuting) and a perceived sense of social wellbeing. This was considered to manifest differently by age, gender and ethnicity. A sense of improved social status, freedom, sexual prowess, empowerment and security were all manifestations of the perceived social wellbeing that car commuting could bring. The role of advertising and the media in perpetuating these connections was also widely acknowledged. The increasing level of use and acceptance of car dominance for the trip to work and for other trips was also considered to perpetuate this connection.

![Figure 6-15 “Car culture” and social wellbeing](image)

In addition to developing preliminary versions of each sector separately, I developed a simpler version of the sectors connected into an overall preliminary model, to demonstrate how the different sectors were inter-related (Figure 6-16).
The conceptual model is dominated by reinforcing loops. This reflects the focus of most participants on problems within a growth dominated system (in this case car commuting). A greater focus on the effects of attempted policy interventions, or what the limits to the growth in car commuting might be, would have resulted in the identification of a greater number of balancing loops (section 5.2).
6.4.2. Workshop 2

The second three-hour workshop was held in July 2009 at the local council, with eight participants. Six of these people had been present at the first workshop and for two participants this was their first engagement in the project.

The workshop involved both a presentation and small-group work. The aims of the project were re-stated and a brief summary of the outcomes of the interviews and the first workshop were presented. The themes emerging from the first workshop were presented, grouped into their sectors.

I then spent some time introducing SD language and concepts using simple analogies. Stocks and flows were described using a bathtub and tap analogy, and the two different types of feedback loops were demonstrated using a simple population model. The STELLA® software was used to show how these concepts could be represented and simulated using the computer software.

We then posed a list of questions that an SD model of commuting and wellbeing might answer, including the following possible questions:

1. If the present trend in increasing car use continues, what are the consequences for community wellbeing?
2. Are the alternative transport choices better for wellbeing?
3. What are the most important influences on choice in the trip to work?
4. Are there points at which policy interventions can be effective?

The second part of the discussion was more contentious, as it related to how we were going to use language in the development of the model, in ways that promoted both consensus and equity. The diversity of participants meant that the naming of variables and relationships emerging from the interviews and the first workshop varied widely. The ways that inequities were discussed or ignored also varied across the groups, as did the willingness to acknowledge those existing or potential inequities.

In particular, I wanted to initiate a discussion about how we should treat Māori concepts of wellbeing and environment in the development of the model. Two potential problems were identified with the inclusion of Māori concepts and terms in the model. Firstly, one policy stakeholder expressed difficulties trying to incorporate and translate Māori models...
of health into practical policy changes. Secondly, there was concern that an incomplete understanding of such models, concepts and terms would result in their misuse and continue a historical process of cultural colonisation. It was therefore recommended that such use should be carefully considered and accompanied by extensive work on understanding and interpretation.

Following these initial discussions, the preliminary causal loops that had been developed were introduced as components of a whole system structure, in a presentation that built the system sector by sector (Figure 6-16). This enabled participants to see that each sector did not stand alone, but was connected to the other sectors into a larger whole. The causal loop diagram for each sector was then briefly introduced.

Participants were then divided into three groups to discuss each sector in detail. Large scale printouts of the sectors had been distributed among the tables, with a facilitator at each table. A text box included with each sector elucidated some of the generic stocks by giving examples of specific terms participants had used in their interviews. This allowed participants to see their own words in the more generic or high level stocks, and also kept the discussion focused on the structure of the causal loop diagrams rather than specific examples for particular stocks (such as the factors contributing to high quality public transport).

Participants were asked to work their way through the feedback loops, discuss and critique them, write comments on the diagrams and re-draw as necessary. At the bottom of each causal loop diagram, I also provided a reference mode for the main stock or stocks for each sector showing trends to the present time. Participants were asked to draw both their ideas of the “business-as-usual” projected trend and their desired trend for each stock. These desired trends can be seen as a set of goals desired by stakeholders that could be used by policy-makers in changing the transport system to alter commuting patterns.

All the participants understood the causal loops well and they engendered lively discussion and debate which all the participants were able to take part in. Many of the discussions also moved from being about the structure of the system to considerations of policy interventions. This occurred for sectors where there was strong consensus that the causal loops clearly and accurately represented ideas about the system.
Stakeholders who were not present at the workshop were offered individual meetings timed for their convenience. I met with three stakeholders individually and they provided further comments on the preliminary causal loop diagrams. These comments were combined with the discussions from the workshop.

Discussions about each sector are summarised below, including a brief description of the projected and desired trends.

**Sector 1: Pedestrian and cyclist injury**

Most participants considered that the positive loops in this sector were acting more strongly than their balancing counterparts at the present time. For example, participants thought that the “safety in numbers” loop was stronger than the “more walkers/cyclists, more injuries” loop. There was wide consensus that the outcomes of walking and cycling to work relating to Toiora (e.g. increased physical activity) outweighed the risk of injury at a population level. Participants also agreed that household economic savings needed to be included as an important positive outcome of walking or cycling to work rather than using the car or public transport. Differences between walking and cycling were also emphasised. In particular, it was considered that the link between injury and being deterred from active modes was much stronger for cycling than it was for walking. This led to the suggestion that these modes would need to be separated in any simulation.

The main stock for this sector was pedestrian and cyclist injuries. Participants found the reference mode for this sector difficult, particularly thinking about cyclist injuries. It was considered that the crude number of cyclist injuries had been declining over time and may continue towards zero, but only because the level of cycling was dwindling, rather than because conditions were improving for cyclists. This made proposing a desired trend more difficult. Participants were concerned that cycling and walking were becoming less safe, but that cycling injuries in particular may decline as the number of cyclists declined. The shared hope was that cycling and walking to work would increase without a concomitant increase in the number of cyclist and pedestrian injuries.

Some policy recommendations also started to emerge. Firstly, participants suggested that investment and regulation to improve the safety of cyclists and pedestrians should occur ahead of the demand to prevent an increase in injuries (strengthening the “safety by design” feedback loop). Secondly, that lower speed limits should accompany reductions
in congestion to ensure that reduced car commuting did not enable the remaining cars to travel faster.

**Sector 2: Public transport infrastructure and services**

There was agreement about the structure of the two reinforcing loops in this sector. As with walking and cycling, participants emphasised the need to include potential household economic benefits of public transport commuting when it came to simulating outcomes for wellbeing.

Members of the group considered that wellbeing objectives do play a part in supporting the funding of public transport infrastructure, even though they don’t strongly influence the commute mode decisions of individuals. This link between wellbeing outcomes and planning for public transport was considered to be missing and needing further consideration.

A further thread of discussion was about the need to change the variable “privatisation of public transport providers”. There was agreement that the issue wasn’t necessarily privatisation, but how this occurred within a structure of public transport governance, and how the privatisation was balanced with public subsidy and regulation. Some particular aspects of privatisation, such as a lack of integration between companies, a focus on shareholder profit and inequitable distribution of services, were considered more important than privatisation *per se*.

The expected trend in public transport services and infrastructure was one of improvement. However, there was a gap between expected and desired levels of improvement. In addition, an aggregate trend was considered to hide likely inequities in improvement between neighbourhoods with a possible gradient by deprivation.

**Sector 3: Neighbourhood sense of safety from crime**

Although there was wide agreement with the structure of this reinforcing loop, participants needed clarification in the sector that this was about social connection within the neighbourhood. The term “community” has a variety of meanings, and was not considered to be related only to local neighbourhoods. There was disagreement about the influence of car commuting on neighbourhood social connection and sense of safety from
crime. While some participants thought the dominance of car commuting had a strong negative influence on people’s sense of neighbourhood community and that car use had led to a geographical scattering of social focus, others considered land use, safety by design (e.g. street lighting) and wider changes in the way people connect with each other socially to be more important.

There was consensus that the trend was for a continuing gradual decline in people’s sense of safety from crime in their neighbourhood, linked closely to a declining loss of neighbourhood social connection. The desired trend was for people to feel safer and more connected in their neighbourhoods over time.

**Sector 4: Time, family responsibilities and accessibility of employment, goods and services**

There was general agreement with the structure of the “individual need for speed adds to population consequences” reinforcing loop.

The other two reinforcing loops in this sector hinge on the relationship between “urban design for public transport, walking, cycling” and the distance to work and appropriate goods and services. Participants argued that this variable was expressing the opposite of sprawl (or car-focused urban design). It was agreed that using one of these terms instead would make sense of the relationships between variables. Participants also considered that “Access to appropriate goods and services” implicitly meant “...by non-car modes of transport” as, even with greater sprawl, access by car may not be difficult.

There was agreement that both the number of children and the level of whānau responsibilities were important and should be included. However, participants argued that the inclusion of “ethnicity” as a variable was meaningless as it could not increase or decrease. There was also a shared sense that “ethnicity” was a proxy for Māori or Pacific. The relationship between ethnicity, the number of parents at home and the number of children was considered to be more complex than portrayed. It was suggested that differences by ethnicity may be better addressed by undertaking separate simulations or stratifying outcomes by ethnicity.

Time pressure on individuals and families was agreed to be increasing over time and was expected to continue increasing into the future. This was considered to be negative for wellbeing, but no alternative desired trend was proposed. It was agreed that average
distance to work was likely to be increasing and that a desired future would either level this trend off or decrease the average distance to work through mixed land use patterns and less sprawl. Participants agreed that access to destinations by public transport, cycling and walking was decreasing over time, and that a desired trend would be in the opposite direction. However, access by car to a wide range of goods and services was considered to have improved, except for during congested peak times. This improvement was not projected into a desired trend by participants. For example, participants were not openly willing to sacrifice the “freedom” of car access for improved access by other modes.

**Sector 5: Workplace support**

There was consensus agreement about the structure for this sector. It was suggested that large organisations were likely to have a powerful influence as advocates, not just for transport infrastructure, but for urban land use that created attractive destinations close to employment, supporting more public and active transport.

It was widely agreed that the level of workplace support for public and active transport has been falling, and would continue to decline without intervention. The desired trend was for workplace support for these modes to increase in the future, by providing incentives for public transport use, walking and cycling. This would require the removal of what were seen as perverse incentives (such as parking requirements in new business developments and tax incentives for company cars) and their replacement with incentives consistent with desired trends (such as requirements for cycling facilities).

**Sector 6: Participation in urban planning and governance**

Participants considered that improvements in satisfaction with urban planning centred on planning decisions being responsive to and delivering on the input of communities and that non-delivery on the expectations of participating communities could be more harmful to social wellbeing than non-participation. On the other hand, some stakeholders acknowledged that it was difficult for community participants to move from a locality focus to regional considerations.

Although participants agreed with the “satisfaction leads to participation” and the “wellbeing from participation in decision-making” reinforcing loops (R1 and R2), they did not support the link between car commuting and the kind of regional empowerment-related social wellbeing implied by the R4 feedback loop.
The importance of equity-focused leadership was also discussed. The need for high level leaders to have clearly articulated values about equity and responsiveness to community needs was considered vital for a sense of trust in the planning process.

Stakeholders were optimistic about future trends in the quality of urban planning, despite agreeing that the quality of planning had been declining over time. This was largely because they felt positive about pending changes to the Auckland’s governance structure. The unification of six local government organisations into a single unitary Auckland Council was considered likely to result in more unified planning and therefore improved outcomes.

Sector 7: Environmental health and cultural wellbeing

This sector was considered the most problematic and was the subject of the least agreement. Although there was agreement about the impact of vehicles on air and water quality, my preliminary attempt to link Māori concepts such as kaitiakitanga and mauriora with more universal ideas about environmental stewardship and cultural wellbeing were rejected by many Māori and non-Māori participants. The links between cultural wellbeing and car commuting were also debated. There was agreement with the postulated relationship between car commuting, loss of connection with the natural environment and therefore less environmental responsibility. However, there was less support for a sense of environmental responsibility leading to action to protect the environment. Disagreement about the structure of this sector meant a reference mode was not discussed.

Sector 8: “Car culture”, marketing stereotypes and social wellbeing

There was wide agreement about the influence of car marketing on the connection between car use and social wellbeing (particularly social status and sexuality), and agreement that this increased the likelihood of people commuting by car. However, this was not universally considered a feedback loop. Although increasing car commuting is likely to increase the connection between car use and social wellbeing, the design of the built environment was perhaps considered a stronger influence. There were other influences that were also considered to play a significant role in the close connection between car use and social wellbeing in our culture. These include the intimate connection between cars and young people’s transition to adulthood in New Zealand, and
with characteristics of freedom, control and independence considered an inherent part of New Zealand culture.

Participants agreed that a desired trend would be for the connection between car use and social wellbeing to decline in the future. They were optimistic that this could happen if the availability of other modes of transport to work improved as the convenience and affordability of car ownership and use declined.

6.4.3. Meetings with the Māori Steering Group

Six meetings of the Māori Steering Group were convened during the development of the causal loop diagrams. These meetings were held at local and regional government offices, a marae, a community centre and the University. Attendance ranged from two to seven members, with most meetings having five or six members in attendance. A changing group attended over time, making a consistent thread of discussion difficult to maintain, despite provision of information to all members between meetings. More iterative strategies for discussion were therefore devised. These included telephone and in person discussions between meetings and time at the beginning of meetings to reiterate the aims, context and direction of the project and review the group’s previous decisions.

Early discussions focused on the research methodology. The group questioned the validity of SD modelling for representing Māori knowledge and requested further consideration of the methodology from a Māori perspective. This was undertaken in collaboration with senior Māori colleagues. We found one example of a research project where SD modelling had been used with Māori participants (Cole, 2007). Although the authors identified limitations with the way that SD modelling was used in the study, they concluded that the method had potential to be successful in a cross-cultural context. This research and further discussions about SD modelling strengths and weaknesses increased the group’s confidence in the method.

The group identified the absence of previous research into the links between transport and Māori wellbeing as a significant issue. Although efforts to engage Māori participants in the project were commended, there was an agreed need for some further Māori-centred research. This led to the development of a separate study consistent with Kaupapa
Māori principles. This qualitative piece of research (the *Transport Patterns and Whānau Ora* study) has been completed and the results disseminated as a brief lay summary and a report designed for communities, non-government organisations and policy-makers.

A persistent topic of debate concerned whether a Māori model of wellbeing, and Māori concepts should be incorporated into a shared model of commuting and wellbeing. The group identified competing tensions that continued to be problematic. These included the need to “stay true” to Māori world views about transport and wellbeing, avoiding specific issues for Māori communities becoming lost in the aggregation involved in creating a parsimonious model; the need to avoid the colonisation and misuse of Māori concepts and language; and concerns about a separate process of research and modelling being ignored by decision-makers. Negative experiences supporting each of these concerns were shared by group members.

Although these tensions were not resolved, the significance of concerns about including concepts of Māori wellbeing and *kaitiakitanga* in the model were sufficient to exclude these from the final versions of the feedback loops, although concepts of Māori wellbeing from published health models were retained in the high level overview diagrams.

The Māori Steering Group continues to be involved with the dissemination and use of the research findings, including how the information from the study might be appropriately combined with some of the findings of the *Transport Patterns and Whānau Ora* study for influencing policy decisions.

6.4.4. Review of the causal loop diagrams with stakeholder organisations

The causal loop diagrams were refined as a result of the second workshop, individual meetings with stakeholders and the discussions of the Māori Steering Group. All stakeholders were encouraged to facilitate presentations of the refined model with the organisations they were representing to gain wider feedback about the model. Half to one hour meetings were convened with five of the stakeholder organisations:

- Manukau Disabilities Steering Group
- Manukau City Council Treaty of Waitangi Committee

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19 Research situated within a Māori cultural framework, designed and undertaken by Māori for Māori use, using methods consistent with and connected to Māori philosophies and principles, and with emancipator and empowerment aims (L. T. Smith, 1999; S. Walker, Eketone, & Gibbs, 2006)
Only one participant chose to present the causal loop diagrams herself. This presentation to the Manukau Disabilities Steering Group was facilitated by the participant, who also presented many of the causal loop diagrams.

Discussions arising from these meetings and workshops demonstrated that the causal loops were well understood by a wide variety of stakeholders. Although there were suggestions for minor changes, a significant proportion of the discussions focused on how aspects of the causal loops were relevant to the interests of each group. There were also comments on the usefulness of the conceptual model for understanding the potential impacts of different policy options.

The feedback from all workshops and meetings led to refinements to the causal loop diagrams and their titles. The refined “working version” of the qualitative model is described in the next section.

### 6.5. Working version of the qualitative model

The working versions of the causal loop diagrams are summarised below. The number of feedback loops emerging from the qualitative modelling meant that simulating all sectors was beyond the scope of the thesis. While some sectors were central to the aims of the thesis and the purpose of the model, others were outside their scope. The prioritisation of a single sector to simulate was made in the context of the Auckland region’s governance upheaval and was therefore undertaken at a workshop of co-investigators (Section 1.6) rather than with all stakeholders. Each causal loop diagram was considered against the following questions to determine a priority sector for simulation:

1. Are outcomes related to wellbeing and sustainability endogenous to the feedback loops?
2. Is the sector within the theoretical scope or boundary of the model?
3. How important is the sector to the diverse stakeholders?
4. Do data sources exist to populate the sector?
These considerations are briefly discussed with the working version of each sector presented below. The high level concept diagram demonstrating the wellbeing outcomes (Figure 6-7) remains a useful overview for the working version of the model.

**Sector 1: Pedestrian and cyclist injury**

Injury as a health outcome is an intrinsic part of the feedback loops in this sector. The sector was considered to be within the boundary of the model’s scope, and important to stakeholders. Many of the variables were also thought likely to be available as part of routinely collected regional and national datasets. Evidence for the shape of relationships between some variables was also likely to be available.
Sector 2: Relative attractiveness of public transport

In addition to being informed by the stakeholder interviews, workshops and meetings, this sector also uses dynamic theories about congestion, road building, induced traffic and the consequences for public transport proposed by Sterman (2000, pp. 178-190).

No health or environmental outcomes are endogenous to this sector, but it was considered to be within the boundary of the model, and important to stakeholders. Many of the variables are available in routinely collected datasets, and others are likely to be available on request from local government agencies. Evidence for the shape of the relationships between variables is less likely to be available.

Figure 6-18 Relative attractiveness of public transport

Explanatory notes: The quality of public transport can be measured by the frequency of services; trip times; disability accessibility; passenger satisfaction surveys. Public transport revenue includes both ticket revenues and government subsidies.
Sector 3: Neighbourhood sense of safety from crime

This sector was also within the boundary of the model, and neighbourhood social connection could be considered as part of social wellbeing. Although the loss of social connection was agreed by stakeholders to be one possible outcome of transport policies that encouraged car commuting, it was not clear whether social connection was directly amenable to change by transport policy, and this was not one of the sectors of highest priority to most stakeholders.

Sector 4: Time pressure and accessibility of employment

Time pressure and family responsibilities are not in themselves wellbeing outcomes, but were identified by most participants as being significant influences on their commuting behaviour. The feedback loops within this sector were also considered to be within the boundary of the model. Although transport policies were unlikely to be able to directly relieve family and work pressures, there are potential points of leverage for transport planning within the feedback loops, including designing public transport services that were responsive to the real needs of busy families, and could compare favourably with commuting by car. Aspects of access to goods and services were also previously included as an endogenous feedback loop in this sector. However, these were considered to be outside the scope of the model, while acknowledged as a further influence on time pressure through family responsibilities.
Chapter 6 – Development of the qualitative model

Figure 6-20 Time pressure and accessibility of employment

Explanatory notes: Family/whānau responsibilities were considered to be determined by age, gender, ethnicity, number of children and household income, all closely inter-related. They are also moderated by the accessibility of other goods and services that are considered healthy (such as healthy food choices and primary care) and culturally appropriate (such as Kura Kaupapa, churches and community services).

Sourcing data to create a simulation version of this model was considered to be very difficult. In particular, developing relationships between family-level time pressures, car commuting, car-focused urban design and the ability to live a convenient distance from work would be particularly difficult because of differences in time scale and significant time delays (as denoted by the double lines across arrows in the diagram). Nevertheless, the causal loop diagram itself provides some policy insights by indicating the leverage points available to transport policy makers described above.
Sector 5: Workplace support

Explanatory notes: Workplace support includes the provision of incentives and amenities for walking, cycling and public transport commuters, as well as the removal of some incentives for driving.

The sector is considered to be within the model’s scope, and of mid-level importance to all stakeholders. However, public health outcomes are not endogenous in the feedback loops and there would be difficulties with attempting to simulate relationships between workplace support, advocacy and investment.
Sector 6: Participation and leadership in transport planning

The sector connecting participation and leadership with commuting behaviours reflects a theory of process. The theories proposed by the stakeholders were closely aligned with my theoretical analysis of the literature, and the emergence of this causal loop diagram could be considered a confirmation of my theories about transport policy process. When considered as an affirmation of these theories, the sector is outside the scope of the model, although fundamental to the work of model-building and transport decision-making.

![Figure 6-22 Participation and leadership in transport planning](image-url)
Chapter 6 – Development of the qualitative model

**Sector 7: Environmental and cultural wellbeing**

Environmental outcomes were considered to be within the scope of the model but these are not present in the feedback loops for this sector. Stakeholders considered the relationships in this sector to be an explanation of why environmental awareness or stewardship was not a stronger influence on commuting behaviour, despite the quality of the urban environment being an influence on where people chose to live, when they could afford to make such choices. Therefore it was unclear whether the feedback loops in this sector were within the scope of the model.

![Diagram of Environmental and cultural wellbeing](image)

*Figure 6-23 Environmental and cultural wellbeing*

Explanatory notes: For tangata whenua there are particular rights and responsibilities relating to the physical environment and natural resources encompassed in kaitiakitanga
Very little is known about the nature of the relationships in these feedback loops, and no data is available. Many of the variables and relationships relate to stakeholder values and are contentious.

**Sector 8: “Car culture” and social wellbeing**

This sector was considered within the scope of the model and of moderate importance to stakeholders, although no public health outcomes are endogenous. The shared view that the connection between car use and social wellbeing was likely to wane over time, as people became more aware of the negative impacts of car use and the availability of other transport options improved, meant that this sector was not considered a high priority for simulation.

![Figure 6-24 “Car culture” and social wellbeing](image)

However, stakeholders identified some policy insights from the qualitative feedback loops, particularly about the need for more positive marketing of public and active transport in the media.

### 6.6. Summary

The process of developing a robust, consensus-based conceptual SD model of commuting and wellbeing described in this chapter included four preparatory and modelling steps. The identification of appropriate stakeholder participants was followed by the development and refinement of causal loop diagrams through: in depth stakeholder
interviews; the analysis of cognitive maps; and workshops and meetings with stakeholder organisations.

The resulting model consists of eight sectors, each containing one to four feedback loops. A total of 21 feedback loops were identified. All but two were positive reinforcing loops. The model sectors describe the major forces influencing commuting behaviour. Almost all the connections between commuting and public health identified in the literature review were also identified collectively by participants, indicating alignment between participants’ understandings of health and an ecosystem health model. However, the participants’ focus on time pressure and stress contrasted with the academic emphasis (particularly in the public health literature) on physical health aspects of transport such as air quality and injury. Although a range of public health outcomes of commuting patterns emerged, few were considered to influence commuting behaviour. The most notable exception to this was the influence of actual and perceived risk of injury on walking and cycling, considered to have a particularly strong influence on cycle commuting.

The experience of undertaking the qualitative part of a participatory SD modelling process also identified a number of challenges for using the method for regional urban planning and in the context of poor existing community participation processes. These challenges include identifying community stakeholders to consider regional urban policies, and maintaining stakeholder participation over a series of workshops involving a significant time commitment to a problem (exponential growth in car commuting) that lacks a strong sense of place-based stakeholder ownership.

The large number of sectors and feedback loops identified meant we needed to prioritise the sectors according to: relevance within the scope of the model; whether wellbeing and environmental sustainability were an endogenous part of the feedback loops; and the feasibility of developing relationships that were able to be simulated. The pedestrian and cyclist injury model best met these criteria, and was therefore chosen for the simulation modelling part of the study.

In the next chapter, the focus shifts from a local focus and qualitative understanding of commuting and wellbeing, to a regional level simulation model. The feedback loops comprising the pedestrian and cycling injury sector are used to develop a simulation model to demonstrate the likely outcomes of policies designed to increase the commuting mode share of cycling.
Chapter 7. Development of the cycling simulation model

Following the development of the commuting and public health qualitative model, the study co-investigators prioritised the sectors by referring to the scope and questions of the thesis and considering the importance of each sector to stakeholders. We decided to create a simulation model focused specifically on the feedback loops associated with cycling. In particular, we wanted to evaluate the effects of policy interventions on cycling mode share and the associated public health outcomes by incorporating the feedback loops from the active transport injury sector of the qualitative model. Although the simulation of all sectors of the conceptual commuting and wellbeing model was outside the scope of the thesis, combining the conceptual feedback loops with a simulation model for one sector is a way of testing the usefulness of SD modelling to transport decision-makers and other stakeholders.

This chapter describes the development and testing of a simulation SD model relating to cycle commuting, based on the active transport injury feedback loops described in the last chapter. The commuter cycling simulation model is included in the accompanying CD for exploration and simulation.

In addition to the cyclist injury outcomes that are endogenous to the feedback loops, appropriate data were available to model four other outcomes: physical activity mortality, air pollution morbidity and mortality, fuel cost savings and greenhouse gas emissions.

As described previously (Section 5.4), at the time the simulation modelling was being undertaken the major upheaval in Auckland’s local governance structure occurred. The structure of transport policy-making changed with the formation of a Council Controlled Organisation (Auckland Transport) operating at arm’s length from the Council and governed by an appointed Board. During this period many of the relationships I had developed with council decision-makers, including the Regional Transport Committee and transport policy analysts, were lost due to organisational changes. The modelling process needed to be adapted to this new political environment. Furthermore, the focus of the modelling changed from a place-based qualitative understanding of commuting and wellbeing to the incorporation of data into a model that could simulate the regional aggregate outcomes of changing transport policy. Consequently, the stakeholders who had been involved in the development of the conceptual model were no longer as
engaged. Rather than the planned development of the simulation model using a participatory process, this part of the study involved a more technocratic process of model development, data identification and incorporation. The process involved many small group discussions with technical, policy and planning stakeholders to discuss assumptions and relationships between variables.

The development and rationale for the main structures, equations and parameters in the simulation model are described in this chapter. The complete model structure and the full list of equations are included as part of the model file on the accompanying CD.

**7.1. Overview of the simulation model structure**

The simulation model uses the feedback loops identified in Sector 1 of the qualitative model (see Section 6.5), applying these to cycle commuting in the Auckland region. Figure 7-1 demonstrates the specific feedback loops represented in the structure of the simulation model. Figure 7-2 presents a high level overview of the causal structure in the simulation model, by demonstrating links between the model’s sub-sectors.

The causal loop diagram (Figure 7-1) only contains variables that are endogenous to feedback loops influencing the absolute number of commuter cyclists (“cyclists” in the diagram). There is a wide range of exogenous factors that also influence commuter cycling. These include fuel price, workplace facilities and social marketing. Although these are likely to have an influence on the magnitude of cycling outcomes, they are unlikely to significantly alter the pattern of behaviour over time because they are not part of the feedback loops driving trends.

For simplicity, I have combined real and perceived risk of injury in the causal loop diagram. The reality is more complex and the two are separated in the simulation model. For example, some kinds of infrastructure may influence the perception of safety without altering the real risk of injury and it is likely that the real risk of injury has some direct influence on the perception of safety.
Chapter 7 – Commuter cycling simulation model

Figure 7-1 Causal loop structure underpinning cycle commuting simulation model

Figure 7-2 Cycling simulation model structural overview
There are eight sub-sectors in the model and each of these are described in detail in this chapter, including theoretical frameworks, causal structures, data sources and fit with historical data where relevant. Simulations of the model take 1991 as the baseline (1991 was a census year) and project through to 2050. This provides 20 years of historical simulation and 40 years of projected simulation. Where possible, baseline data from 1991 were therefore used to populate the model. Where data specific to the Auckland region were unavailable, national data were used. For some parameters no data were available. In these cases the parameter estimates were either tuned to historical data (for dependent parameters) or best judgement was used to estimate values.

The remainder of the chapter describes the sub-sectors in detail. Each section includes a rationale based on the evidence from the literature and a description of the model structure, followed by sources of data and assumptions for specific parameters and relationships.

7.2. Stock and flow structures

The main stock-and-flow structures in the model describe the growth over time of the commuting population and the way these commuters are apportioned between the four main modes of transport available for commuting: light vehicles, bicycles, public transport and walking.

7.2.1. Commuting population

Growth in the commuting population was simulated using the simple feedback structure demonstrated in Figure 7-3. The baseline employed population and the commuting fractions were calculated from 1991 census labour force statistics (Statistics New Zealand, 2009, p. 88) and validated against the three more recent censuses, as well as population projections for the Auckland region. Projections undertaken for the Auckland region by Statistics New Zealand (Statistics New Zealand, 2009) suggest that the growth in the labour force is likely to be similar to the overall population growth, with a 40% increase expected by 2031.
Chapter 7 – Commuter cycling simulation model

The employed population was taken to be the number of people employed full time and part time. Not all employed people travel to work on a particular day. A proportion of the employed population on any day will either not work, or work from home. The commuting fraction was therefore calculated from the census Main Means of Travel to Work (MMTW) question\(^{20}\) as the proportion of people travelling to work on census day. This has stayed fairly constant at approximately 0.85. The model assumes no intervention to increase telecommuting or part time work and therefore no future change in this fraction.

7.2.2. Commuting mode share and vehicle kilometres travelled

The population travelling to and from work on any particular day (commuters) are divided up into four different commute modes: light vehicles (driver or passenger of a car, van or motorcycle); bicycle; walking; and public transport (bus and heavy rail). The stock and flow structure is identical for each mode, as demonstrated in Figure 7-4. Baseline stock values are from the 1991 Census MMTW question, rounded to the nearest 10,000 (Table 7-1).

The mode share for each commute mode is determined by the relative utility of each mode, explained by a range of influences, which are described in the next section.

\(^{20}\) This work is based on Statistics New Zealand’s data from the Census of Population and Dwellings, licensed by Statistics New Zealand for re-use under the Creative Commons Attribution-Non-commercial 3.0 New Zealand license, provided March 2011
Chapter 7 – Commuter cycling simulation model

EQUATIONS:

\[ \text{Car Commuters}(t) = \text{Car Commuters}(t - dt) + (\text{change in driving to work}) \times dt \]

\[ \text{Change in driving to work} = \frac{((\text{Commuters} \times \text{car mode share}) - \text{Car Commuters})}{\text{time to change behaviour}} \]

Figure 7-4 Commuting mode share stock and flow structure

<table>
<thead>
<tr>
<th>Mode</th>
<th>Mode share</th>
<th>initial stock values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light vehicle</td>
<td>0.849</td>
<td>288765</td>
</tr>
<tr>
<td>Public transport</td>
<td>0.075</td>
<td>25464</td>
</tr>
<tr>
<td>Bicycle</td>
<td>0.021</td>
<td>7171</td>
</tr>
<tr>
<td>Walk/jog</td>
<td>0.055</td>
<td>18600</td>
</tr>
<tr>
<td>Baseline commuters</td>
<td></td>
<td>340000</td>
</tr>
</tbody>
</table>

Table 7-1 Baseline stock values based on MMTW question 1991 census

The census MMTW question has some inherent limitations. The question asks only about the trip to work on census day and only about the main means of travel, which is explained as the mode used for the longest distance. Active modes and public transport are likely to be affected by asking only about census day, as they may be undercounted if weather on the census day is inclement. However, I have tested this assumption for the most recent five censuses and found no correlation between reported precipitation levels
on census day and the cycling mode share reported by the MMTW question. Walking and cycling are also likely to be underestimated as they are often used in combination with public transport. In these trips public transport makes the greatest contribution to distance travelled and is therefore counted as the main mode.

Although it only covers a single day’s travel, the aggregate information from the MMTW question is routinely used as a proxy indicator for the regular travel habits of commuters. Using the MMTW question to examine trends over time and to model changes in commuting behaviour assumes that individual responses are correlated over time, with little within-person variation in travel mode. At an aggregate population level where the focus is on structural influences, this is likely to be acceptable.

There is a delay between a change in any influence on mode share, such as fuel price or infrastructure improvements, and a change in commuting behaviour. This is known as inertia in mode choice and has been analysed in transport behaviour studies (Gärling & Axhausen, 2003). For example, recent research (Cantillo, Ortúzar, & Williams, 2007) has used random inertia effects to simulate mode change using typical stated and revealed preference data. This research demonstrates firstly that omitting inertia leads to forecasting errors, and secondly that inertia is likely to be normally distributed with a balance between the “hyper-ready” for change and those who are more resistant. However, the time taken to change behaviour at an aggregate level in long term dynamic models has not been studied. As a starting point I have used 1 year as a default inertia time (time to change behaviour) and have tested the fit of the model to a range of variations in this assumption (Appendix D). It is possible that inertia is different across modes and in different transport systems (Yáñez, Cherchi, & Ortúzar, 2009), but there are no data about this difference for the Auckland region, and very little internationally to assist with incorporating such differences.

The annual number of vehicle kilometres travelled (VKT) by commuting light vehicles is calculated from the light vehicle mode share, accounting for average commuting vehicle occupancy (since a proportion of light vehicle commuters are passengers), annual trips (accounting for part and full time employment) and the median light vehicle commute trip length.
Chapter 7 – Commuter cycling simulation model

7.3. Influences on mode share

7.3.1. Rationale

Observations consistent with a theory of relative attractiveness of public transport and car use emerged from the qualitative interviews and workshops (see Figure 6-18). A relative attractiveness theory has also been used extensively in stated choice models to understand mode utility and mode choice. In their book synthesising research about stated choice modelling for transport, Louviere, Hensher and Swait (2000, pp. 2-3) describe pertinent underlying principles, where mode share is determined by both measurable properties of the system and the perception of those properties. SD resource allocation or market share models based on the relative attractiveness of discrete product choices are also relevant. I have adapted the SD modelling resource allocation archetype to develop the structure of the mode share model. Although the term “relative attractiveness” is usually used in these models, this term was contentious in the workshops with stakeholders, as there was a sense this implied a level of choice and agency that was not experienced in Auckland’s transport system. I have therefore used the term “utility” to encompass a range of criteria including availability, safety, quality, reliability and attractiveness.

The relative utility of each mode determines the mode share at an aggregate level. Sterman (2000, pp. 544-545) outlines the generalised structure for this archetype. Adapting this, in a problem of allocating commuters among a number of alternative modes $n$, in a system with a total commuting population $C_T$, the share of commuters travelling by each mode is given by the mode's utility $U_i$, relative to the sum of all mode utilities in the following generalised equations:

$$ C_i = S_i \times C_T \quad (7-1) $$

$$ S_i = U_i / \sum_{k=1}^{n} U_k \quad (7-2) $$

$$ U_i = f(u_{i1}, u_{i2}, \ldots, u_{im}) \quad (7-3) $$

The relative utility is influenced directly by aggregate population perceptions of a number of criteria, $u_{ij}$, determining overall utility. These perceptions are influenced by properties of the different transport modes such as safety and reliability. There may be $j = 1, \ldots, m$ determinants of utility, however the share of commuters distributed to any mode is always
bounded by zero and one, and the total share always equals one. The underlying formulation of utility $U_i$ is given by the following product of individual criteria:

$$U_i = f_1(u_{i1}) \times f_2(u_{i2}) \times \cdots \times f_m(u_{im})$$

(7-4)

Each individual effect on mode utility can then be modelled using any appropriate linear or non-linear function. This is a relatively simple formulation compared with typical mode choice models. Despite this it fits historical data reasonably well and contributes to a parsimonious and widely comprehensible structure.

The model privileges the structural constraints on commute mode choice over the psychological or social influences. This is supported by international experience where changing the transport environment has successfully resulted in changes in mode share. It is also consistent with the dominant influences described by stakeholders in the qualitative modelling. In particular, many stakeholders emphasised the lack of choice in making decisions about mode in the trip to work, particularly feeling constrained by a lack of public transport options, an unsafe environment for active transport, and urban design that enforces car reliance to meet a range of work and family responsibilities.

7.3.2. Model structure

The model structure for all mode utilities follows the same basic configuration, demonstrated by the public transport utility example in Figure 7-5. The utility of each mode is calculated by the non-weighted product of all the influences on utility, which are drawn from surveys about the perception of transport modes, but are in turn affected by real changes in the system. The mode share is calculated as the utility of the mode divided by the total utility of all modes. Mode utility is a non-zero sum (the utility of one mode can increase without detracting from the utility of other modes) but all relative utilities (mode utility/total utility) shift with mode utility changes so that the sum of all mode shares is always one.
Chapter 7 – Commuter cycling simulation model

**EQUATIONS:**

\[ \text{PT utility} = \text{PT always or mostly safe} \times \text{PT good for work} \times \text{PT hassle free} \times \text{PT normal} \times \text{PT price ok} \times \text{PT work trip in range} \]

\[ \text{Total Utility} = \text{LV utility} + \text{cycling utility} + \text{PT utility} + \text{walk utility} \]

\[ \text{Mode share PT} = \frac{\text{PT utility}}{\text{Total Utility}} \]

*Figure 7-5 Structure of the utility of commute modes and commute mode shares using the “market share” archetype (Sterman, 2000) (only public transport shown to demonstrate the structure of all modes)*

Policy interventions can be simulated that influence one or more aspects of mode utility and create feedback with other parts of the model. The model assumes that when the mode share of one mode increases, commuters are drawn proportionately from the other modes. Similarly, the result of a decrease in the mode share of one mode is to spread the change in commuters proportionately to the mode share of alternative modes. These assumptions are difficult to test empirically in a system where many criteria determining mode utility are changing over time.

The parameters influencing mode share were developed from the qualitative interviews and workshops, as well as the Auckland Regional Council’s transport perceptions surveys (2010b), which asks respondents a range of questions about each mode, including questions relevant to commuting. Price, convenience, safety, distance to work and a sense
of whether the mode was a “normal” (or usual) way to get to work all emerged as influences on mode utility from the conceptual modelling part of the study.

7.3.3. Parameter estimation

Six determinants of utility were modelled. Data for four of the six influences were available from the transport perceptions surveys held every two years since 2000 (Auckland Regional Council, 2000, 2002, 2004, 2006, 2008, 2010b). The surveys are structured telephone interviews with a random sample of 1000 Auckland households, using a single respondent aged over 13 years per household. The surveys include questions about car use, motorcycling, public transport, walking and bicycling, using consistent questions longitudinally. For each question the report provides data about the percentage of respondents answering each categorical option. Most questions relate to all trips rather than commuting, although one question asks whether each mode is a good option for taking work or study trips. Questions asking specifically about leisure or shopping trips were excluded from use in the model. Answers to questions for all trips about convenience, safety and cost were assumed to apply equally to commuting trips. The determinants of mode share able to be populated from this data were the percentage of respondents for each mode who considered the mode “good for work”, “price OK”, “always or mostly safe”, and “hassle-free”. Data from all the available surveys were used to develop trends for each criterion. These trends were then used to extrapolate back to estimate 1991 baseline values. The modelled criteria determining mode utility, their data sources and baseline values are summarised in Table 7-2.

Estimates for the “work trip in range” determinant were calculated from an analysis of distance to work in the whole of New Zealand undertaken by Statistics New Zealand using the MMTW question (Goodyear & Ralphs, 2009). Where the survey data showed little change in the value of a criterion over time a single value was used, while graphical functions were used where there were recognisable trends (for example an increase in the proportion of people considering light vehicles always or mostly safe).
### Data sources and initial values for criteria determining mode utility

<table>
<thead>
<tr>
<th>Determinant of mode utility</th>
<th>Source of data</th>
<th>Notes</th>
<th>Initial values (1991)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Good for work</strong></td>
<td>ARC transport perceptions surveys</td>
<td>Total of those responding that the mode is a good option for all or most trips to work/study</td>
<td>LV 0.65</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cycling 0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Public transport 0.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Walking 0.12</td>
</tr>
<tr>
<td><strong>Price OK</strong></td>
<td>ARC transport perceptions surveys</td>
<td>Those responding that price is no hindrance for each mode – data only available for car and public transport, assumed to be 0.95 for cycling and 1.0 for walking</td>
<td>LV 0.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cycling 0.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Public transport 0.85</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Walking 1.0</td>
</tr>
<tr>
<td><strong>Always or mostly safe</strong></td>
<td>ARC transport perceptions surveys</td>
<td>Total of those responding that the mode is always or mostly safe</td>
<td>LV 0.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cycling 0.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Public transport 0.62</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Walking 0.52</td>
</tr>
<tr>
<td><strong>Hassle-free</strong></td>
<td>ARC transport perceptions surveys</td>
<td>Total of those responding that they can get around quite or extremely well using each mode (not asked for public transport, judgement used)</td>
<td>LV 0.52</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cycling 0.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Public transport 0.24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Walking 0.47</td>
</tr>
<tr>
<td><strong>Work trip in range</strong></td>
<td>Analysis of census data (Goodyear &amp; Ralphs)</td>
<td>All work trips assumed to be within range for light vehicle and public transport, trips under 6km assumed to be possible to cycle and trips 2km and less able to be walked</td>
<td>LV 1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cycling 0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Public transport 1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Walking 0.27</td>
</tr>
<tr>
<td><strong>Normal</strong></td>
<td>Stakeholder discussions</td>
<td>Interpretation of interview and workshop data, fine tuned to historical mode share data</td>
<td>LV 0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cycling 0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Public transport 0.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Walking 0.89</td>
</tr>
</tbody>
</table>

Table 7-2 Data sources and initial values for criteria determining mode utility
A recent community survey in Christchurch, New Zealand (Kingham, Taylor, & Koorey, 2011) found that approximately 10% of those surveyed stated they would not cycle to work under any circumstances. An upper limit to the potential commute mode share of cycling was included in the model in two places: firstly, an upper limit of 0.9 was placed on the proportion of people who could consider cycling always or mostly safe; and secondly an upper limit of 0.9 was placed on the proportion of people considering cycling a good mode for work. One limitation in the survey question about mode safety is the conflation of safety from injury with a sense of personal security. Personal security is particularly important for public transport and walking and was identified as an issue by many of the participants in the qualitative modelling.

Mode share data from the two censuses during the period of the surveys (2000-2010) were used to validate the determinants and the mode utility equations and fine tune the “normal” criterion (Section 7.9.2 and Appendix D).

### 7.4. Cycling injury outcomes

Three of the four feedback loops emerging from the qualitative model relate to postulated influences on actual and perceived cyclist safety from injury. In addition to identifying data for individual parameters and relationships, in the development of this sub-sector I also used existing data to analyse whether the postulated feedback loops were likely to be active in the Auckland commuting system.

#### 7.4.1. Rationale

Road accident prediction models have used generalised linear models since the 1980s (Hauer, Ng, & Lovell, 1989) and have been developed to consider a range of aspects of road design, vehicle flows, vehicle safety technologies and post-crash responses (Bhalla, et al., 2007; Elvik, et al., 2009, pp. 35-37; Hauer, et al., 1989; S. Turner, Roozenburg, & Francis, 2006). When considering crashes involving more than one vehicle, these models take the following generalised form (adapted from Elvik, et al., 2009, p. 58):

\[
I = \alpha Q_{\text{Mode}_1}^{\beta_1} Q_{\text{Mode}_2}^{\beta_2}
\]

(7-5)

where

\[
I
\]

is the number of injuries,
Chapter 7 – Commuter cycling simulation model

\( Q_{\text{Mode } n} \) is the number of road users of mode \( n \),
\( \alpha \) is a constant specific to the combination of modes, and
\( \beta_n \) is a non-linear coefficient determining the likelihood of injury.

Bhalla, et al. (2007) have described a specific version of this generalised equation to consider the dynamic effects of changing mode share, but assumed linear coefficients affecting injury fatalities. They used a two-step approach to predict fatal injuries between modes: firstly calculating the likelihood of collision, \( c \), and then calculating the likelihood of fatality (case fatality ratio, \( r \)). For vulnerable road users being struck by vehicles, their equation takes the form:

\[
\text{Fatal injury}^{\text{threat}}_{\text{victim}} = c^{\text{threat}}_{\text{victim}} \times r^{\text{threat}}_{\text{victim}} \quad (7-6)
\]

where the likelihood of collision is a function of the number of road users of each mode, distances travelled by those users, and a constant encompassing a range of vehicle, driver and system attributes.

A number of different denominators have been used to describe road traffic injury rates in general, and cycling injury rates in particular, depending on the research question. These include death and injury rates per kilometre travelled, rates per vehicle owned, rates per capita and rates per trip. In the case of car crash injury, rates per capita are useful in considering the likelihood of injury where the entire population can be assumed to be exposed. All of these denominator choices have limitations (Halperin, 1993). For instance, when comparing road traffic injury between countries, different rates of vehicle ownership and vehicle kilometres travelled need to be accounted for. In this study, the research question relates to the way cycling injuries influence whether people consider cycling to work. A denominator that corresponds with the way risk is considered by individuals when making a mode choice is therefore required. I have assumed that the question individuals ask themselves (if they consider cycling safety) takes the form: “What is the likelihood I will be injured or killed this year if I decide to cycle to work”. Furthermore, I have assumed that commuters may make this consideration periodically (rather than every time they make a commute trip) and that they weigh up their risk by thinking about the visible order of magnitude of cyclists on the roads and the number of injuries and deaths they are aware of. Since we are considering short commuter trips,
where there are not large differences in the average length of trips across the modes, accounting for trip distance differences is also less important. I have therefore used the number of commuter cyclists as the denominator and calculated an injury rate per 1000 cyclists as the most useful rate for influencing the cycling mode share. Using commute-time specific injury statistics across modes allows some adjustment for differences in risk by trip type (since commute trips occur under a set of specific spatial and social circumstances that may make them more dangerous).

Like Bhalla, et al. (2007), I have taken a two step approach to predicting the risk of commuter cyclist injury as a function of cyclist and vehicle numbers (Equation 7-5). However, I have also incorporated non-linear coefficients for the effects of vehicle numbers and system attributes, in keeping with the generalised linear equation (Equation 7-6) and with Elvik’s recent review (2009a) of the non-linearity of risk for pedestrians and cyclists with changing numbers. Combined fatal and serious injuries are modelled using this approach, and injuries on local (residential or neighbourhood) streets are modelled separately from arterial (main, carriageway or trunk) roads.

Serious and fatal injuries are assumed to result from collisions between light vehicles and cyclists. Almost all serious cyclist injuries in New Zealand involve a motor vehicle (S. Turner, Binder, & Roozenburg, 2009) and collisions with light vehicles (as opposed to heavy vehicles such as trucks) are amenable to changes in the commute mode share.

### 7.4.2. Model structure

The model includes five steps for the dynamic calculation of commuter cyclist fatal and serious injuries, as well as the rate of injuries per 1000 commuter cyclists:

1. Estimation of the baseline proportion of vehicles and cyclists on local and arterial roads at peak time
2. Calculation of the baseline annual rate of commuter cyclist-car collisions in the Auckland region
3. Calculation of the annual number of cyclist-car collisions, accounting for the non-linear effects of changing car and cyclist numbers
4. Calculation of the number of serious and fatal injuries, accounting for the non-linear effect of changing mean car speeds on each type of road
5. Calculation of the annual serious and fatal injury rate per 1000 cyclists, accounting for the changing number of commuter cyclists

The overall structure is shown in Figure 7-6 below.
7.4.3. Parameter estimation

Proportion of peak time light vehicles and cyclists on local and arterial roads

A study of commuter cyclists in Guelph, Canada (Aultman-Hall, Hall, & Baetz, 1997) using GIS21 to analyse the routes of 1500 cyclists, found that in the absence of any bicycle lanes 46% of the travel was undertaken on arterial roads and 49% on local roads, with the remainder on a small number of off-road cycle paths. No data were available to estimate these parameters in Auckland; therefore researcher and stakeholder judgement (J. Valero, personal communication, March 14, 2011) was used to make an initial assumption that at peak time 90% of light vehicles and 50% of cyclists were on arterial roads and this assumption was tested in the sensitivity analysis (Appendix D).

Initial annual collision and injury rates

Cycle collisions were analysed using data from the New Zealand Transport Agency Crash Analysis System (CAS)22, which are based on fatal and serious injury crashes reported by the police, as well as road categorisation data. The electronic CAS system contains information about the timing, location, travel mode, people involved, injury categorisation and the crash environment (Land Transport New Zealand, 2005).

All cyclist injuries for the Auckland region were extracted from the database for 1990-2009, categorised as fatal, serious and minor injuries23. A separate 5-year aggregate analysis of crash hour (2005-2010) was used to estimate the proportion of all cycle injuries occurring in peak times, assumed to be 0700-0900 hours and 1500-1800 hours on all days of the week24. These two time periods accounted for about 40% of all reported cyclist fatalities and two thirds of serious injuries. A further aggregate analysis of the same data by age group demonstrates that across the three injury severity categories, approximately 90% of all injuries occurred in the working age group.

21 Geographic Information System
22 CAS is an online database of all crashes reported to the police. It has limited direct access, but requests can be made through the New Zealand Transport Agency (NZTA) for data extraction http://www.nzta.govt.nz/resources/crash-analysis-system/cas.html
23 Candidate’s analysis of data extracted from CAS by Lynette Billings, Performance Information, NZTA, May 2010
24 Candidate’s analyses of data extracted from CAS by Lynette Billings, Performance Information, NZTA, June 2010
There is considerable evidence for the under-reporting of even serious cyclist injuries (Aultman-Hall & Hall, 1998; Elvik, et al., 2009, pp. 50-51, 155), including evidence from New Zealand (Alsop & Langley, 2001; S. Turner, et al., 2006). S. Turner, et al. (2006) compared hospitalisation, ambulance and CAS reports in Christchurch, New Zealand, suggesting there is little overlap between the datasets and that CAS data represents approximately half of the serious injuries reported across the three datasets. It is not clear whether the lack of overlap represents the reporting of different injuries, or poor data recording for the same injuries. An earlier survey including cyclists of all ages in Christchurch (Christchurch Cycle Safety Committee, 1991) found a reporting rate of all cyclist collisions of approximately 20%. Assuming this survey is generalisable to other New Zealand cities, it suggests that every 100 urban car-cyclist collisions result in about 40 injuries serious enough to be reported to CAS, while only 20 to 30 of these are actually reported.

**Light vehicle numbers at peak times**

Commuting vehicles are not the only light vehicles on the road at peak time generating collisions and injuries for cyclists. The baseline proportion of all light vehicles at peak time assumed to be commuting was derived from the Auckland Regional Transport Model Version 3, which uses a figure of approximately 60%, derived from Auckland Household Travel Survey data (J. Valero, personal communication, March 25, 2011).

**Impact of car numbers on collisions**

Separate non-linear graphical functions were developed for local and arterial roads based on modelling for New Zealand undertaken by S. Turner, et al. (2009). Different baseline numbers of vehicles between these two different road categories at peak times means that a change in vehicle numbers has a different effect on the likelihood of a cyclist-light vehicle collision on each kind of road. Turner’s modelling analyses the effect of vehicles on single stretches of road (as opposed to area-wide) and is shown in Figure 7-7.

Using the lowest cycle volume curve in Figure 7-7, local and collector roads in the Auckland region with vehicle volumes of between 1 and 10,000 vehicles per day fall into the section of the graph where doubling vehicle numbers doubles collisions. The upper bound of vehicle numbers in Turner’s analysis is lower than average flows on many of

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25 ART3 is the four-step land use and transport model developed by Sinclair Knight Merz Ltd, Beca Infrastructure Ltd and David Simmonds Consultancy for the Auckland Regional Council
Auckland’s arterial roads. I have assumed the relationship over the whole range of vehicle flows is S-shaped, in other words at higher vehicle flows such as those found on arterial roads, the relationship between increasing vehicles and vehicle-cycle collisions becomes less steep. Both graphical functions are shown in Figure 7-8.

Figure 7-7 Cycling collision rate with constant cycling numbers and changing motor vehicle numbers (S. Turner, et al., 2009)
Figure 7-8 Effect on collisions of changing vehicle numbers (adapted from S. Turner, et al., 2009)

Impact of cycle numbers on collisions

There has been a great deal of interest in the international active transport literature about the concept of “safety in numbers” for cycling over the last decade, prompted by Jacobsen’s ecological study (2003) demonstrating a non-linear association between cyclist numbers and injuries across cities in the US, UK and Europe. The conclusion drawn from this study (and others replicating its methods such as Robinson, 2005; Vandenbulcke, et al., 2009) is that increasing the number of cyclists reduces the risk of injury per cyclist or per kilometre travelled by bicycle through a “safety in numbers” effect. In New Zealand, a recent study (Tin Tin, Woodward, Thornley, & Ameratunga, 2011) has found a similar ecological relationship between per capita hours spent cycling and city level injuries per million hours spent cycling. However, there are a number of limitations inherent in these studies. They are generally cross-sectional and therefore not well designed to distinguish cause from effect and they do not account for the differences
in cycling infrastructure between cities. Despite this, a causal inference continues to be
drawn in reviews of the literature (de Nazelle, et al., 2011; Elvik, 2009a) and among
policy-makers (Bhatia & Wier, 2011). Recent critical review (Bhatia & Wier, 2011;
Wegman, Zhang, & Dijkstra, 2010) has argued for caution in drawing such inferences,
and highlights the possibility that increasing infrastructure improves safety and thereby
encourages greater cycling – “numbers in safety”.

To explore the possibility of a safety in numbers feedback loop in Auckland, a region
with very low levels of cycling infrastructure (that has changed little over time) and a
historical drop in the number of cyclist trips over time, I set up a simple model to
compare historical commuter cycling injury data with modelled data that included the
influence of cyclist numbers. If there was a safety in numbers effect acting in Auckland,
an increase in the cycling injury rate would be expected to accompany a drop in cyclist
numbers. I used the simple structure to test this hypothesis with two simulations:

Run 1: Constant injury rate
Run 2: Safety in numbers effect in keeping with power function estimates by Jacobsen

These results of these runs comparing modelled and historical cyclist injuries are
demonstrated in Figure 7-9 below.
The two runs demonstrate that activating a safety in numbers loop in keeping with Jacobsen’s assumptions worsens the fit between the modelled and historical cycle injuries compared with a constant cyclist injury rate. If anything, the historical data suggests that the historical reduction in cyclists has been accompanied by a slight reduction in the cycling injury rate (the opposite of what would be expected with a safety in numbers effect).

Together, this preliminary analysis of historical data and the likelihood that infrastructure plays a large role in the relationship between cyclist numbers and injury rates, led me to separate these effects in the cycle commuting simulation model. In keeping with Bhatia
and Wier (2011) I have included an initial numbers in safety effect (in other words effective infrastructure encourages more cycling); no safety in numbers effect at the current low levels of cycle commuting; and a mode share threshold, beyond which a modest safety in numbers effect is likely to occur. The strength of the non-linear relationships seen in the ecological studies are therefore shared roughly equally between the effect of safety infrastructure and a safety in numbers effect. I have initially chosen a conservative threshold related to a mode share of 10% before the initiation of the safety in numbers effect occurs. An option to switch to a full “Jacobsen” safety in numbers effect is built into the model for comparison and I have also tested the sensitivity of the sub-sector to a lower threshold (Appendix D).

The shape of the curves reported in Jacobsen, et al. are described by a binary power function, where each doubling of cyclist numbers leads to a further reduction in the risk of collision by 34%. For the modified effect, at cycling levels above 10% of the commute mode share (or about 70,000 cyclists) I have assumed a reduction in risk of 17% for every doubling of cycling numbers. At time \( t \), the relative risk of collision \( RR_{\text{collision}} \) is therefore given by the following equations:

\[
RR_{\text{collision}} = 0.83^{\beta_t}
\]

(7-7)

where

\[
\beta_t = \log_2\left(\frac{\text{cyclists}_t}{\text{cyclists}_{t=0}}\right)
\]

(7-7)

**Average car speed**

Peak time vehicle speeds on arterial roads are measured in the Auckland region in an ongoing series of annual surveys, with data available from 2004-2010 (BECA Infrastructure Ltd, 2011). These measurement surveys report a stable average peak time arterial speed of 28-30 km per hour over the past seven years. The surveys do not measure peak time speeds on local roads. These have been assumed to remain comparatively uncongested, and the results of a separate study monitoring indicative local roads (Charlton, et al., 2010) have been used (45 km per hour). Both the mean speed and the speed distribution (often indicated by the 85th percentile speed) are likely to be important indicators of road traffic injury risk (see for example Frith & Toomath, 1982; Keall, Povey, & Frith, 2001), although the relationship between speed variance and injury
Chapter 7 – Commuter cycling simulation model

risk found in older studies have recently been questioned (Elvik, 2009b). Although 85th percentile free-flowing traffic speeds are reported for Auckland roads, peak time measurements of speed are taken for congestion monitoring purposes and therefore peak time 85th percentile speeds are not currently reported.

Impact of average car speed on collision injury ratio

A well documented cumulative frequency curve exists relating vehicle impact speed to the likelihood of serious injury and fatality for vulnerable road users, particularly pedestrians (Organisation for Economic Co-operation and Development & European Conference of Ministers of Transport [OECD & Ministers], 2006; Rosén, Stigson, & Sander, 2011). As there is no cycling-specific curve, I have assumed the shape of the curve for cyclists is similar to that for pedestrians. There are a number of other problems with translating data from the curves reported in the literature into the simulation model. Firstly, the most recent review of the relationship for pedestrians (Rosén, et al., 2011) addresses the bias towards serious and fatal injuries seen in previous studies, re-affirming the shape of the curve but finding much lower fatality ratios across the speed range. However, this review relies on European data, where the car fleet is newer and the post-accident response may differ from New Zealand. Adjusting for the likely overall undercount of cycling injuries, as well as the bias towards reporting serious and fatal injuries, the rate of cyclist injury during commute times in Auckland (7.6% on average26) is much higher than that reported by Rosén and Sander (2009) for similar speeds.

Secondly, the relationship in the simulation model is between average vehicle speeds and the probability of a serious or fatal injury to cyclists. An assumption is made in the literature that impact speeds are lower than travelling speeds due to braking before a collision (Anderson, McLean, Farmer, Lee, & Brooks, 1997; Elvik, Christensen, & Amundsen, 2004). However, the relationship between travelling and impact speeds has rarely been quantified. A single study by Walz, Hoefliger and Fehlmann (1983) found that in most crashes collision speed was at least 20% less than travelling speed.

To model the effect of changing average light vehicle speeds rather than impact speeds I have therefore used the curve reported in the OECD Speed Management report (OECD & Ministers, 2006), centred it on existing Auckland data (adjusted for the expected

26 My own analysis of CAS data for the Auckland region 1990-2009
undercount of minor injuries) and shifted the curve to the right by 10 km per hour in keeping with the estimated relationship between travel and impact speed.

**Impact of injury numbers on cycling sense of safety**

Modelling the effect of the real risk of cycling injury on commuters’ perceptions of cycling safety completes three of the four theoretical feedback loops (R1, R2 and B1 in Figure 7-1), by influencing the commute mode share of cycling. There is support for perceived sense of safety being the most significant influence on cycling from a number of studies exploring barriers to cycling among adults in cycling environments similar to that found in Auckland (Daley, Rissel, & Lloyd, 2008; Pooley, Horton, Scheldeman, & Harrison, 2010; Winters, Davidson, Kao, & Teschke, 2010). From these studies it appears that the perception of safety drawn from the presence of cycling infrastructure is a strong influence, and likely to be more influential than the real risk of injury (Kingham, Taylor, et al., 2011). However, in Auckland many people who cycle for transport have either experienced a collision with a motor vehicle themselves or are likely to know cyclists who have. In a recent survey of those taking part in a New Zealand cycle challenge (Thornley, Woodward, Langley, Ameratunga, & Rodgers, 2008), the incidence of a significant crash in the previous 12 months was 0.5 per cyclist per year (a third with an injury serious enough to need medical attention). Although this is not a generalisable population and did not distinguish cyclist-only crashes from collisions with motor vehicles it provides some indication of the high incidence of cyclist injuries. Examining crash data for the four census years between 1991 and 2006 allows an estimate of annual collision rates for commuter cyclists, adjusting for likely levels of under-reporting. These ranged from 73 per thousand cyclists per year to 1 in 10 cyclists per year. These figures suggest that the real risk of injury is also likely to act as a deterrent to commuter cycling.

I have included a non-linear effect for the number of fatal injuries on the proportion of people considering cycling to be always or mostly safe as shown in Figure 7-10.
Chapter 7 – Commuter cycling simulation model

EQUATION:

\[
\text{Cyc always or mostly safe} = \min(0.9, (\text{baseline cyc always or mostly safe} \times \text{effect of reported injuries on sense of safety}) + \text{infrastructure effects on sense of safety})
\]

Figure 7-10 Effect of reported fatal injuries on cycling perception of safety (default delay in perception response is 1 year, and the default assumption is that all fatal cyclist injuries are reported in the media)

The formulation for the perception of safety equation indicated in Figure 7-10 makes the infrastructure effects stronger than the effect of actual fatality rates on perceived safety, in keeping with the literature.

7.5. Air pollution outcomes

7.5.1. Rationale

Estimates from the Health Impacts of Air Pollution in New Zealand (HAPiNZ) modelling study were used as the basis for simulating the community-wide morbidity and mortality effects of air pollution attributable to commuting in the Auckland region. The methods for this study have been described previously (Section 2.2.1). The study quantifies the following annual health outcomes attributable to three different pollutants (PM$_{10}$, carbon monoxide – CO, and benzene):

- Mortality due to PM$_{10}$ and carbon monoxide (separately)
- Cardiovascular and respiratory hospital admissions attributable to PM$_{10}$ and CO
- Hospital admissions for chronic obstructive pulmonary diseases (COPD) due to PM$_{10}$
• New cancer (leukaemia) diagnoses attributable to benzene
• Restricted activity days due to particulates (a fraction of PM$_{10}$ is used as a proxy for finer particles)

Region- and source-specific estimates were included in the HAPiNZ analyses, enabling the estimation of the burden of disease in the Auckland region attributable to motor vehicle pollution. Vehicle kilometres travelled (VKT) per square kilometre was found to be the best predictor of vehicle-related air pollution in the HAPiNZ models, and was used to develop metrics for each outcome (levels of increase in the outcome per increase in square kilometre VKT). In recent work (Lindsay, et al., 2011) we have converted this density VKT metric for the HAPiNZ outcomes into linear VKT metrics for New Zealand.

For this analysis I have calculated Auckland region linear VKT metrics for each of the HAPiNZ outcomes from the region-specific modelling updated in 2010 (Kuschel & Mahon, 2010) and Ministry of Transport total regional VKT estimates for the same year (Ministry of Transport, 2011b). Using the earliest analysis in the HAPiNZ update (2001), I have extrapolated back to 1991 accounting for changes in the exposed population, and used these as the simulation model baseline metrics.

There have been, and continue to be, “business-as-usual” improvements in vehicle emissions per VKT over time, spread unevenly across different classes of vehicle in the New Zealand fleet. Improvements have been strongest in the light vehicle fleet, and this is projected to continue over time. An Auckland region-specific Vehicle Emissions Prediction Model (VEPM 5.0$^{27}$) has been developed and updated to track and predict changes to fuel consumption and a range of emissions across different vehicle classes. This model enabled adjustments to the VKT burden of disease metrics over time to account for non-linear improvements in PM$_{10}$ emissions from the light vehicle fleet.

There are a number of significant assumptions in the HAPiNZ and VEPM models, as well as necessary assumptions in using the outputs of the two models to simulate the effects of changing commuting light vehicle kilometres travelled. Table 7-3 summarises these

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$^{27}$ The beta version of VEPM 5.0 was made available prior to its official release for the analyses in this research by its principal author Keith Jones, Department of Mechanical Engineering, University of Auckland
assumptions, whether they result in an under- or over-estimation of effect, and the likely
size of the error based on discussions with a range of local air pollution experts.\(^{28}\)

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Direction of error</th>
<th>Likely size of error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removing vehicles at peak time has the same effect as removing “average” emissions in a 24 hour period</td>
<td>Underestimate – congested travel, low dispersion during morning peak</td>
<td>Up to 3 times</td>
</tr>
<tr>
<td>Removing commute vehicles has the same effect as removing an “average” fleet vehicle</td>
<td>Overestimate – light vehicles emit less PM(_{10}) but more oxides of nitrogen</td>
<td>Not known</td>
</tr>
<tr>
<td>HAPiNZ only accounts for mortality in people aged over 30 years</td>
<td>Underestimate – there is likely to be some burden of mortality in people aged less than 30 years</td>
<td>Small</td>
</tr>
<tr>
<td>HAPiNZ assumes exposure occurs in people’s small area of residence</td>
<td>Possible underestimate – greatest acute exposures during congested trips, workplace areas may have higher air pollution than residential areas, but most of the burden is in susceptible populations who tend to spend more time in their area of residence</td>
<td>Small</td>
</tr>
<tr>
<td>HAPiNZ assumes PM(_{10}) is a good proxy for the burden of disease from all emissions</td>
<td>Increasingly an underestimate – light vehicle PM(_{10}) improvements occurring more rapidly than oxides of nitrogen, particles &lt;10(\mu)m may be improving more slowly</td>
<td>Not known</td>
</tr>
</tbody>
</table>

Table 7-3 Significant assumptions in the air pollution burden of disease simulation

The summary table indicates that most of the assumptions lead to an underestimate of the burden of disease, with the potential for the burden of disease to be up to three times more than estimated. An analysis of the effect of these assumptions is included in the sensitivity analysis (Appendix D).

The effect of altering commute mode share may also have an effect on air pollution exposure for the commuters undertaking the mode shift. As discussed in Section 2.2.1 particular attention has been given to assessing the difference in exposure between commuting by car and by bicycle. De Hartog, et al.(2010) concluded from their review of

\(^{28}\) Ian Longley, National Institute of Water and Air Research (NIWA); Gerda Kuschel, Emission Impossible Ltd; Simon Hales, Department of Public Health, University of Otago; and Alistair Woodward, School of Population Health, University of Auckland
exposure studies that shifting from vehicle to cycle commuting is associated with an increase in exposure to fine particles. However, this is likely to occur in a population of healthy workers who contribute little to the overall burden of disease from air pollution and I have not included these effects in the simulation model.

7.5.2. Model structure and parameter estimation

The air pollution burden of disease simulation structure is demonstrated below (Figure 7-11). Two steps are involved. Baseline burden of disease metrics are adjusted for population and fleet emissions changes over time, to calculate an adjusted per commuting VKT burden for the region. This is then multiplied by the total commuting VKT travelled to estimate the burden of disease attributable to light vehicle commuting in the region’s population.

The baseline burden of disease metrics are given in Table 7-4.
Figure 7-11 Structure for simulating air pollution burden of disease due to light vehicle kilometres travelled (adj – adjusted, hosp – hospitalisations, COPD – chronic obstructive pulmonary disease hospitalisations, RAD – restricted activity days)

Table 7-4 Baseline values for air pollution burden of disease per 100m light vehicle kilometres travelled (adapted from HAPINZ update 2010 (Kuschel & Mahon, 2010) and Ministry of Transport data (Ministry of Transport, 2011b))
Light vehicle fleet PM$_{10}$ emissions

The VEPM 5.0 model was used to analyse business-as-usual trends in PM$_{10}$ emissions for the light vehicle fleet from 2001 to 2030. Expected fleet emission improvements are built into the model based on Ministry of Transport historical and projected changes in fleet composition, fuel compositions and fleet turn over. The model allows user-defined inputs for ambient temperature, average speed and trip length (down to 8km). Some adjustment for cold start trips can also be made. Using the average Auckland temperature (16°C centigrade), 8km trips at 30kph, and including PM$_{10}$ from tyres and brakes, the following indicative trend in emissions is predicted (Figure 7-12):

![Figure 7-12 Historical and projected trend in PM$_{10}$ light fleet emissions 2001-2030 (analysis using VEPM Version 5.0 beta)](image)

The shape of this curve was extended back to 1991 and forward to 2050 to calculate an adjustment metric for the PM$_{10}$ burden of disease over time. The shape and extent of the emission improvements projected for the light vehicle fleet by the VEPM model closely reflect those seen in Europe, the UK and the US, with a lag of about 10 years, due to the slower fleet turnover in New Zealand and delayed implementation of fleet emissions standards (Longley, Coulson, & Olivares, 2010). Specific longitudinal fleet emissions measurement data are also available for Auckland (Bluett, Kuschel, Rijkenberg, & Shrestha, 2011). Random light vehicle fleet measurements of carbon monoxide, nitrous
oxide and uvSmoke (a proxy for particulates) were taken in 2003, 2005 and 2009. Reductions seen in these direct measurements over time are of a similar magnitude to those modelled in the VEPM, adding further to confidence in the VEPM projections.

7.6. Physical activity

7.6.1. Rationale

The cohort studies examining commuter cycling as a source of physical activity exposure, with either all-cause mortality or cardiovascular mortality as an outcome, have been described previously (Section 2.2.2). The three most robust prospective studies, adjusting for leisure time physical activity suggest a relative risk of mortality for commuter cycling of 0.64-0.8 (Andersen, et al., 2000; Hu, et al., 2004; Matthews, et al., 2007). Of these three studies only Andersen, et al. and Matthews, et al. undertook separate analyses for cycling. The commuter cycling aspects of these two studies are described in detail below to explain differences in exposure assumptions, age groups, lead times and effect sizes.

Andersen, et al. combined three cohort studies in Copenhagen with an average follow-up of 14.5 years. The commuter cycling part of the study included approximately 7000 men and women, although 90% of this group were men. The age range of participants in the overall study was 20-90 years, but the range was not reported for the commuter cycling group. The average time spent cycling for work was three hours per week. Questions about leisure- and commute-time physical activity were asked a number of times over the follow-up periods for each cohort. Although the commuting part of the study was unable to be analysed by age, the leisure-time physical activity analysis demonstrated a similar reduction in all-cause mortality regardless of age group. This reduction in all-cause mortality was also seen for both sexes in the commuting analysis, with an overall relative risk of 0.72 (95%CI 0.57 – 0.91), adjusted for cardiovascular risk factors and leisure time physical activity.

Matthews, et al. report an analysis from the Shanghai Women’s Health Study, a cohort of approximately 70,000 women aged 40-70 years, followed up for six years. Transport cycling was analysed in three categories: 0, 0.1-3.4, and ≥ 3.5 MET hours/day. The study analysed the independent effects of commuter cycling on all-cause mortality, adjusting for other kinds of physical activity, including leisure-time, household and occupational activities. Taking 1MET hour as 15 minutes of commuter cycling (Ainsworth, et al.), the
middle category of commuter cycling in this study is equivalent to the measure of exposure used in Andersen et al. The relative risk of all-cause mortality reported for this middle group is 0.79 (95%CI 0.61-1.01).

Neither study discussed issues of lead time (the delay between starting to cycle and the full effect on all-cause mortality), or the effect on all-cause mortality of ceasing to cycle to work. The implicit assumption made about lead time in both studies appears to be either that physical activity reported near the beginning of the study continues to influence mortality over a long period (up to 28 years for some participants), or that commuting behaviour is stable enough over time that reports of physical activity at the start of the study are similar throughout follow up. The World Health Organization’s Health Economic Assessment Tool (Kahlmeier, et al., 2011, [WHO HEAT tool]) for cycling assumes a linear accumulation of effect over 5 years, although this was based on author judgement.

For the simulation model, I have made the following assumptions regarding the link between cycling mode share and the effect on all-cause mortality due to physical activity:

1. The proportion of people reporting cycling to work on census day reflects the proportion of people cycling regularly (three times per week or more) to work.
2. Cycling commute trips of 6km or less in Auckland are equivalent to the levels of physical activity reported for commuter cycling in the Copenhagen cohorts and in the middle group of the Shanghai cohort.
3. On average cycling to work in Auckland confers a 28% reduction in all-cause mortality. This implies a linear dose-response association for the range of physical activity likely to be seen for the range of Auckland cycle commutes, and for the range of other physical activity already undertaken by commuters. This is the risk reduction estimate used in the WHO HEAT tool (Kahlmeier, et al., 2011).
4. There is a lead time of two years for the full effect of cycle commuting on all-cause mortality to gradually build up, and a similar time following a reduction in cycle commuting for all-cause mortality to return to the expected rate.

Assumptions three and four have been tested in the sensitivity analysis (Section 7.9 and Appendix D). The dose response relationship between moderate physical activity and all-cause mortality has recently been tested in a systematic review meta-analysis (Woodcock, et al., 2011) and found to be non-linear, with the greatest benefits occurring for inactive
people taking up some physical activity. The size of the effect on all-cause mortality was slightly smaller than assumed here (a 19% reduction in relative risk of all-cause mortality of 30mins/day compare with no activity).

Although differences between population subgroups in the effect of cycle commuting physical activity on all-cause mortality are not reported in the literature, the absolute reduction in mortality will differ by age, ethnicity and sex, because of the different all-cause mortality rates across these groups. In the simulation model analysis of physical activity mortality I have therefore stratified the commuting population by age, gender and ethnicity and applied the risk reduction to changes in commute mode share accounting for existing differences in all-cause mortality across these groups (see Section 7.6.3 below). In addition I have taken simple account of overall historical and projected trends in all-cause mortality over time. Although I have assumed that changes in cycling would occur evenly across the population, this approach allows the simulation of different levels of benefit across these groups, to start a conversation about the equitable distribution of benefits for policy interventions.

7.6.2. Model structure

Figure 7-13 demonstrates the overall structure of the physical activity sub-sector of the model. Four steps are involved in the calculation of all-cause mortality savings from changes in the commute cycle mode share:

1. The projected all-cause mortality is calculated by age group, gender and ethnicity adjusting for widespread trends in all-cause mortality, assuming no change in cycling commute mode share (“business-as-usual” mortality).
2. Any change in cycle mode share is combined with the relative risk estimate to project stratified all-cause mortality rates responsive to these changes in mode share.
3. These rates are applied to the stratified commuting population to calculate the all-cause mortality.
4. The simulated all-cause mortality is subtracted from the projected “business-as-usual” mortality to calculate lives saved (or lost) due to changes in cycle commuting.
Chapter 7 – Commuter cycling simulation model

Figure 7-13 Structure for the simulation of physical activity outcomes of commuter cycling
7.6.3. Parameter estimation

Expected all-cause mortality rates

The commuting population was stratified into four broad age groups between 15 and 69 years, sex and three prioritised\(^{29}\) ethnic groups (Māori, Pacific and Other) in a special analysis of the 1991 MMTW question by Statistics New Zealand\(^{30}\). The earliest mortality data available using a consistent ethnicity definition come from 1996, so 1991 baselines were extrapolated using 1996-1997 data. Two years of national data were aggregated to achieve robust standardised estimates of all-cause mortality by ethnicity, age group and gender, since the number of deaths in the younger working population each year is low. Table 7-5 shows the baseline all-cause mortality rates used in the model.

<table>
<thead>
<tr>
<th>1996-1997 all-cause mortality rates per 100,000 population</th>
<th>Māori Men</th>
<th>Māori Women</th>
<th>Pacific Men</th>
<th>Pacific Women</th>
<th>Other Men</th>
<th>Other Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-24 years</td>
<td>1.7</td>
<td>0.7</td>
<td>1.2</td>
<td>0.4</td>
<td>1.2</td>
<td>0.5</td>
</tr>
<tr>
<td>25-44 years</td>
<td>2.8</td>
<td>1.6</td>
<td>2.0</td>
<td>1.5</td>
<td>1.3</td>
<td>0.6</td>
</tr>
<tr>
<td>45-64 years</td>
<td>15.9</td>
<td>11.3</td>
<td>11.7</td>
<td>7.6</td>
<td>6.0</td>
<td>3.9</td>
</tr>
<tr>
<td>65-69 years</td>
<td>48</td>
<td>33.8</td>
<td>41.3</td>
<td>21.5</td>
<td>22.2</td>
<td>12.7</td>
</tr>
</tbody>
</table>

Table 7-5 All-cause mortality rates by age, gender and prioritised ethnicity per 100,000 population for the whole of New Zealand 1996-1997\(^{31}\)

All-cause mortality rates have been declining over time in New Zealand for all groups. Although this has been uneven across socioeconomic and ethnic groups in earlier decades, the past twenty years (the historical period in the simulation model) have seen a more even pattern. I have used the overall rate of decline from 1996-2006 to create a single near-linear adjustment using historical trends and projecting similar rates of decline into the future (Figure 7-14).

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\(^{29}\) The priority recording method assigns individuals to one mutually exclusive group based on a priority of categories designed to give priority to non-European groups and special priority to Māori, ensuring that important groups are not submerged within the dominant minority. In this case the priority is Māori>Pacific>Other (non-Māori, non-Pacific) (Cormack & Robson, 2010)

\(^{30}\) Data produced by Statistics New Zealand under assumptions specified by the candidate, June 2011

\(^{31}\) Ibid.
Only mortality rates for 15-69 year-olds were included. However, in 1996 there were more than 20,000 people aged 65 and over commuting to work on census day. Over a quarter of these were in their seventies and over 1500 of them aged over 80. Mortality rates for this group of workers are unlikely to reflect the average mortality rate for 65 years and over. Since mortality rates for this group are much higher than younger age groups, they are more likely to contribute to an overestimate of the benefit of increasing cycle mode share. I have therefore assigned this group the national 65-70 years mortality rate, in keeping with a healthy worker effect. In support of this assumption, and somewhat surprisingly, my own analysis of the MMTW question 32 shows that the rate of cycling in those commuters aged over 65 is almost three times the total rate, at approximately three percent.

7.7. Greenhouse gas emissions

7.7.1. Rationale

A similar approach to the calculation of air pollution outcomes was taken to estimate the per vehicle kilometre travelled greenhouse gas emissions. This approach has also been used in previous work to estimate the benefits of increasing cycle trips more generally

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32 This work is based on Statistics New Zealand’s data from the 2006 Census of Population and Dwellings which are licensed by Statistics New Zealand for re-use under the Creative Commons Attribution-Non-commercial 3.0 New Zealand license, provided June 2011
(Lindsay, et al., 2011). The *Vehicle Emissions Prediction Model* (VEPM 5.0) for Auckland includes carbon dioxide (CO$_2$) emissions across different vehicle fleet classes, accounting for past and forecast trends in fuel consumption, fuel composition and technological emissions improvements. The VEPM 5.0 also includes carbon monoxide emissions but does not include methane or nitrous oxide. All three are potent greenhouse gases. The amount of methane and carbon monoxide in petrol and diesel has been changing very little over time; therefore calculations could be made to quantify their per VKT emissions (from combustion of petrol and diesel) using New Zealand’s Greenhouse Gas Inventory (Ministry for the Environment, 2011) and the Ministry for Economic Development Energy Datafile (Energy Information and Modelling Group, 2011). The Fourth IPCC$^{33}$ report includes metrics (Forster, et al., 2007, p. 211) to enable the conversion of methane, carbon monoxide and nitrous oxide emissions into carbon monoxide equivalents (CO$_{2eq}$).

### 7.7.2. Model structure

The structure of the greenhouse gas emissions sub-sector is relatively simple (Figure 7-15).

![Figure 7-15 Structure for the simulation of greenhouse gas emission savings](image)

The model first calculates total metric tons of CO$_{2eq}$ per 100 million vehicle kilometres travelled (VKT) by commuting light vehicles, accounting for trends in light vehicle CO$_{2eq}$

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$^{33}$ Intergovernmental Panel on Climate Change
emissions. These are then converted to annual commuting CO$_{2eq}$ and per capita emissions for the whole regional population.

7.7.3. Parameter estimation

CO$_{2eq}$ emissions per 100 million VKT

Data for CO$_2$, carbon monoxide and fuel consumption for petrol and diesel over 2001 to 2030 were extracted from VEPM Version 4.0, for the light vehicle fleet, travelling the shortest average trips at a 16° centigrade average temperature and 30kph average speed. The built-in cold start adjustment was also included. Historical and forecast changes in the diesel-petrol ratio of the light vehicle fleet are included in VEPM. Methane and nitrous oxide emissions were calculated from fuel consumption and all the greenhouse gases were converted to CO$_{2eq}$ using the IPCC 20-year metrics (methane has 25 times, nitrous oxide has 298 times and carbon monoxide has 1.9 times the warming potential of CO$_2$) to develop a trend over time (Figure 7-16).

![Figure 7-16 Trend in light vehicle CO$_{2eq}$ 2001-2030 from VEPM version 4.0](image)

The trend in CO$_{2eq}$ emissions shown in Figure 7-16 was used to extrapolate a baseline per VKT figure for 1991, and develop a graphical function to simulate the trend to 2051.
Chapter 7 – Commuter cycling simulation model

7.8. Fuel cost savings

Estimating the full financial savings to individuals and households of changing mode share in the trip to work is very difficult. For some households, one adult changing the way they commute will mean the possibility of reducing the number of cars in the household, with significant overall maintenance, insurance, registration and fuel cost savings. For other households, only the direct fuel costs and some proportion of maintenance costs will be saved. For yet other households, the mode change to cycling for the trip to work may mean the deferment of trips for other purposes such as grocery shopping, and therefore little or no real cost saving. There are few data from international studies or from New Zealand about the cost consequences of adults changing from light vehicle use to alternatives for commuting.

Our own preliminary work on the full time and financial costs of travel by different modes in Auckland (Macmillan, et al., 2009) suggests there is also a gradient by deprivation in the proportion of household income spent on petrol and the time taken to travel one kilometre accounting for all time costs, in keeping with previous research (Tranter, 2004).

7.8.1. Rationale

Given the above limitations in our current knowledge about the implications for household income of changing mode share in the trip to work I have initially taken account only of the direct fuel costs saved for average light vehicle commute trips averted. The previously described analysis of light vehicle petrol and diesel fuel consumption using the VEPM 5.0 model was used to develop a fuel consumption trend for 1991-2051. Petrol and diesel fuel cost forecasts have previously been modelled for the Auckland region to support the Regional Land Transport Strategy 2010-2040 (Donovan, et al., 2009). Historical data for fuel prices back to 1991 were extracted from the New Zealand Energy Data File (Energy Information and Modelling Group, 2011). In New Zealand there is a significant difference between the cost of diesel and petrol, making it important to model these two fuels separately. Together these were used to calculate average fuel cost savings in 2008 New Zealand dollars. There is a difference between the price paid “at the pump” for fuel and the price relative to the cost of living. Although analyses of historical fuel prices can examine the real relative cost of fuel for households,
this is more difficult to achieve in forecasts, therefore the nominal “at the pump” costs have been used in the simulation model.

7.8.2. Model structure

The model simulates fuel cost savings in three steps (Figure 7-17):

1. The light vehicle kilometres (LVKT) saved through cycle commute trips are calculated accounting for the median commute trip length, the proportion of full time and part time workers and the average vehicle occupancy

2. LVKT is converted to total volume of petrol and diesel accounting for trends in the ratio of diesel-petrol vehicles in the light vehicle fleet, and trends in fuel consumption

3. Nominal total and per cyclist savings are calculated against historical and forecast price trends
7.8.3. Parameter estimation

Trends in fuel consumption (Figure 7-18) and fuel price trends (Figure 7-19) incorporated into the model are demonstrated below.

Figure 7-18 Modelled trend in fuel consumption (l/km) 1991-2051 extrapolated from VEPM Version 4.0 light vehicle fleet analysis (8km trips, 30kph, cold start)

Figure 7-19 Modelled trends in petrol and diesel prices (in 2008 NZD, extrapolated from Donovan, et al. and MED)
7.9. Formal validation procedures

This section describes the results of the formal validation procedures previously outlined in Section 5.9 and summarised in Table 5-2. Most aspects of direct structural validity were built into the model development process. The use of interviews and participatory workshops combined with reviews of the relevant literature provide some confidence that the important concepts and relationships for considering the effects of cycling policies on commuter cycling and relevant outcomes are included in the model, and that constants and relationships between variables come from best evidence. All equations are dimensionally consistent, and all parameters have real world counterparts. The structure-oriented behaviour procedures and behaviour pattern validity testing are briefly described below.

7.9.1. Structure-oriented behaviour

As described in Table 5-2, structure-oriented behaviour testing included testing for plausible behaviours of simulated parameters under extreme values and identifying parameters to which the model was most sensitive. A summary of the complete sensitivity analysis is described in Appendix D.

In summary, the model demonstrates plausible behaviours under extreme values testing. The behaviour of the model was tested against wide ranges for the most uncertain variables. Each variable was tested individually. Sixteen population sector, mode share and outcome variables were tested using a combination of extreme values and individual Monte Carlo simulations (repeated simulations using random sampling). The model was behaviourally stable to testing for 13 of these. Injury outcomes were behaviourally sensitive to assumptions about safety in numbers, but only when Jacobsen’s full safety in numbers effect was tested. Changes in the behaviour of air pollution outcomes resulted from testing against an extreme range of assumptions about projected improvements in light vehicle PM_{10} emissions, ranging from an early return to increasing morbidity and mortality under a weak improvement scenario, to a continued decline in the air pollution burden of disease through to 2050 under a strong improvement scenario. The outcomes generated were behaviourally plausible under both extremes. Greenhouse gas emission outcomes were behaviourally sensitive to testing across the extreme range of projected improvements in the light vehicle fleet, but again the outcomes simulated were behaviourally plausible.
7.9.2. Behaviour pattern validity

The testing of behaviour pattern validity involved graphical comparisons with historical and projected time series data for transient behaviours. I tested historical and projected labour force population, historical cycling mode share and cycling fatal and serious injuries as these were endogenous variables generated by the model. The fit with historical cycling mode share is shown in Figure 7-20 and the fit with cycling injury is shown in Figure 7-21.

Figure 7-20 Simulated and historical cycling commute mode share

Figure 7-21 Simulated annual fatal and serious cycling injuries compared with historical data (line 2) and a linear trend in historical data (line 3)
The simulated behaviour patterns demonstrate good fit with labour force projections, historical cycling mode share data and cycling injury data. The simulated injuries exclude much of the random variability in the historical data and fit a linear trend in historical injuries.

**7.10. Summary**

In this chapter I have documented the development of the commuter cycling simulation model, incorporating the relevant feedback loops developed in the qualitative phase of the modelling process. Data from a wide range of sources were incorporated into the model. By developing the simulation model using the best data available I have been able to show how transitioning from conceptual causal loop diagrams to a simulation model can test whether theorised feedback loops are operating in the real system. For example, it is questionable whether the safety in numbers loop (postulated by stakeholders and argued in the literature) is operating in Auckland at our current low numbers of cyclists.

The documentation provided in this chapter and the accompanying model file allows full replication of the simulation model by others. Structure assessment tests have demonstrated its dimensional consistency, robustness to extreme conditions and freedom from integration error. Sensitivity testing demonstrated that the model is robust to extreme values testing, with behaviourally plausible outcomes under all extreme values. The model is most sensitive to assumptions about the threshold and strength of the safety in numbers assumption and projected improvements in light vehicle fleet emissions. The model has good fit with the shape and magnitude of historical data, but excludes fluctuations and randomness, particularly in historical cycling injury data. All these aspects of validity contribute to an ongoing process for building confidence in the model.

In the next chapter I describe the use of the cycling model to simulate the effects of a range of cycling policy investments on the model outcomes, and on Auckland’s quantified targets for sustainable transport.
Chapter 8. Policy simulations

The previous chapter described the development of a dynamic simulation model to understand the influences on commuter cycling, and some of the integrated outcomes of changing the mode share of cycling in the trip to work. In this chapter I demonstrate the use of the model for simulating policy scenarios to identify actions that would assist the Auckland region to meet the quantified sustainable transport targets in the Auckland Regional Land Transport Strategy (ARLTS 2010-2040) identified in Chapter 3 (Section 3.2.3). The specific quantified targets for 2040 that are likely to be influenced by policies to increase commuter cycling (among other transport policies) are as follows:

1. Reduction in road deaths to no more than 40 per year and serious injuries to no more than 288 per year (average 2005-2007 was 74 deaths and 537 serious injuries)
2. Congestion on the regional strategic road freight network to remain at or below 2006-2009 levels (average delay of 0.53 minutes per kilometre)
3. Increase in walking and cycling mode share for all trip legs in urban areas to 35% (currently 14% walking and <1% cycling)
4. Halve per capita greenhouse gas emissions from domestic transport based on 2006 levels (6% reduction expected by 2016)
5. Increase in the proportion of people considering cycling always or mostly safe to more than 0.8 (currently 0.19)

The qualitative work, in keeping with the literature about cycling, indicated that policies to improve both actual and perceived safety of cycling were likely to be most effective for increasing cycling to work. In addition to a “no action”, or “business-as-usual” scenario, the model has therefore been used to test the effects of several cycling policies, including the cycling investment planned in the ARLTS 2010-2040, and three alternative infrastructure investment scenarios, chosen from international understandings of best practice. The policies are described in detail and the results of the policy simulations are also described in this chapter. Although there is a growing number of reports that bicycle lanes and paths encourage people to cycle (Buehler & Pucher, 2011; Dill & Carr, 2003; Larsen, 2010; Nelson & Allen, 1997), there is very limited literature comparing different kinds of cycling infrastructure. Many reports from countries with the greatest experience
with implementing cycling infrastructure (such as the Netherlands and Denmark) are not available in English. I have used the available information to develop comparative effectiveness metrics for different kinds of infrastructure. In bringing together the evidence I have to a large extent relied on three reviews: CROW’s Design Manual for Bicycle Traffic from the Netherlands (2007), The Handbook of Road Safety Measures (Elvik, et al., 2009) and the 2009 review of the safety impacts of infrastructure by Reynolds, Harris, Teschke, Cripton and Winters (2009). Of these three sources only Reynolds, et al. (2009) describes the design of studies. These main sources have been supplemented by more recent reports and peer reviewed articles where available.

Once a working version of the simulation model was completed, it was demonstrated to a range of stakeholder groups as a preliminary assessment of its usefulness for supporting advocacy, policy decisions and prioritising interventions. The chapter first describes a best practice approach to the provision of cycling infrastructure and then describes three policy interventions. The results of model simulations using these policies are then reported and policy insights discussed. The full model structure and equations for the policy interventions are included in the accompanying model file.

8.1. Best practice approach to providing for urban transport cycling

The CROW manual for cycling includes a diagram that recommends infrastructure for different road types by traffic volume and 85th percentile traffic speed (p.108). This diagram has been adapted and enhanced in the London Cycling Design Standard (Transport for London, 2005). A simpler version has also been used in New Zealand’s Cycle Network and Route Planning Guide (Ryan, Boulter, & Dorrestyn, 2004). I have used the more complex version from London to guide the design of the best practice interventions simulated in this chapter. This version is shown below in Figure 8-1, with three of the four classifications of Auckland roads (primary arterials, secondary arterials, collectors and local roads) and their 85th percentile speeds. Primary arterials have two-way traffic flows higher than the scale on the graph, and could not be superimposed.
Figure 8-1 Cycle facility recommendations based on motorised traffic volume and speed: Auckland’s road classes are superimposed based on mean measured traffic counts and 85th percentile speeds (red – secondary arterials, green – collector roads, blue – local roads).

Indicative two-way vehicle flows per day for different Auckland road classes are provided below (Table 8-1). Regular measurement surveys of 85th percentile free-flowing (unimpeded) urban speeds are not differentiated by road class. The most recently reported urban unimpeded 85th percentile speed for the Auckland region was 59kph (approximately 37mph) in 2009 (W. Jones, 2010). In their study of the speed effects of traffic calming Charlton, et al.(2010) measured speeds on three different road classes before treatment and reported 85th percentile speeds by road type as shown in Table 8-1.
Table 8-1 Classification of roads in the Auckland region with expected and measured traffic counts and 85th percentile speeds (adapted from Auckland Transport, 2011c; Charlton, et al., 2010; Wallace, 2008)

<table>
<thead>
<tr>
<th>Road classification</th>
<th>Expected two-way traffic volume</th>
<th>Average measured traffic volumes</th>
<th>85th percentile speeds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary arterial</td>
<td>20000-50000</td>
<td>30457</td>
<td>61kph (38mph)</td>
</tr>
<tr>
<td>Secondary arterial</td>
<td>10000-20000</td>
<td>14554</td>
<td>61kph (38mph)</td>
</tr>
<tr>
<td>Collector road</td>
<td>3000-10000</td>
<td>6616</td>
<td>58kph (36mph)</td>
</tr>
<tr>
<td>Local road</td>
<td>Up to 3000</td>
<td>1153</td>
<td>54.4kph (34mph)</td>
</tr>
</tbody>
</table>

The graph and table above indicate best practice approaches to Auckland’s different road classes. In particular, they suggest that primary and secondary arterials should be treated with segregated lanes, and that speeds on local roads should be reduced to create shared quiet roads without requiring segregation between cyclists and motor vehicles. The suggested treatment of collector roads in Auckland is less clear, but the graph suggests these could be treated the same as local roads. This analysis of best practice guides the two universal policy approaches I have taken in Sections 8.3 and 8.4.

8.2. Auckland Regional Land Transport Strategy (ARLTS) cycling network

The ARLTS 2010-2040 includes a commitment to invest in a network of cycling infrastructure (the Regional Cycle Network, abbreviated to RCN in the simulation model). Detailed information about the network was provided by Auckland Transport34. This network approach assumes that some routes are more likely to attract cycle trips than others. In selecting proposed routes, consideration was given to connecting town centres, areas of expected growth, public transport stations and major education facilities. Most of the proposed network follows the route of main arterial roads. The planned infrastructure includes a combination of on-road non-segregated cycle lanes, off-road shared pedestrian and cycle facilities, shared footpaths and shared bus lanes. No specific treatment of local streets is proposed. Of a total of 700km of network to be built by 2040, 96km have not yet been allocated an infrastructure type. These were assumed to be shared among the infrastructure types according to the share of known planned investment. Table 8-2 summarises the network and a map of the proposed network can be found in Appendix E.

34 Data supplied by Brian Horspool, Regional Walking and Cycling Coordinator, Auckland Transport, August 2011
Table 8-2 Proposed Auckland regional cycle network (adapted from data provided by Auckland Transport35)

<table>
<thead>
<tr>
<th>Infrastructure type</th>
<th>Kilometres planned</th>
<th>Proportion of arterial road network treated by 2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-road cycle lane</td>
<td>441</td>
<td>0.46</td>
</tr>
<tr>
<td>Off-road shared path/shared footpath</td>
<td>221</td>
<td>0.23</td>
</tr>
<tr>
<td>Shared bus/bike lane</td>
<td>37</td>
<td>0.04</td>
</tr>
</tbody>
</table>

The different kinds of infrastructure planned will have varying effects on cycling mode share, through their effects on actual and perceived safety, perceptions of the utility of cycling for work and the convenience of cycling. The expected effects of each infrastructure type are therefore described separately below.

8.2.1. On-road cycle lanes

These are marked cycling-only lanes within the road space, designated by any combination of painted lines, coloured surfaces and bicycle symbols. Examples of existing lanes in Auckland are shown in Figure 8-2. The photographs demonstrate the variability in implementation width and quality.

Estimated effects of on-road lanes on the risk of collisions and injuries vary widely. The best designed studies are uncontrolled before-and-after studies and controlled cross-sectional studies which have accounted for differences in cyclist and car volumes, either across time or between study sites. The CROW manual (p. 117) reports research from the Netherlands suggesting cycle lanes were less safe than physically separated tracks, and could be less safe than no infrastructure. This is in keeping with the findings of a Danish before-and-after study (S. U. Jensen, 2008) which compared cycle crashes and injuries following cycle lane implementation, with projected crashes and injuries taking account of changes in motor vehicle and cyclist traffic. An increase in cycling injuries was found both along the roadway and at intersections (overall increase of 50%), although author comments suggest that large changes in traffic volumes were inadequately accounted for in the analysis. Best estimates from the road safety handbook suggest a relative risk of cycle lanes compared with no infrastructure of 0.91 (95% CI36 0.83-1.5, p. 157), although it is unclear how this estimate was calculated from the studies summarised. Two studies

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35 Ibid.
36 95% confidence interval
examining cycle lanes alone reported by Reynolds, et al. Suggest a stronger reduction in self-reported collisions (relative risk of 0.75), although these studies were only adjusted for cyclist km travelled.

Figure 8-2 Examples of on-road cycle lanes in Auckland

I have used the point estimate provided in the road safety handbook and variation in the estimate between 0.75 and 1.5. In addition to the issues of study quality mentioned above, variation in the results of on-road cycle lane studies results from variation in the width and quality of lanes and differences in intersection treatments. The impact on safety is also likely to be affected by the level of respect for the lanes by drivers.
Cycle lanes seem to improve the perception of cycling safety compared with cycling in traffic, particularly for women (Garrard, et al., 2008). However, the effect on perception of safety is stronger when there is physical separation from traffic. This segregation effect has been reported qualitatively in a number of studies including in Australia (Garrard, et al., 2008) England (Wardman, Hatfield, & Page, 1997), and New Zealand (Kingham, Taylor, et al., 2011). The effect of cycle lanes on perception of safety has been quantified in a single survey of cyclists in Copenhagen (S. U. Jensen, Rosenkilde, & Jensen, 2007). As shown in Figure 8-3 the survey found that cycle lanes improve the perception of cycle safety compared with no infrastructure, but had a weaker effect than facilities with physical separation (called cycle tracks in this report).

In keeping with Jensen’s findings, the simulation model includes a region-wide effect on perception of safety related linearly to the proportion of arterial roads treated, up to a maximum increase to 0.7 in the proportion of people considering cycling always or mostly safe if all arterial roads in the region were treated (from a baseline of 0.19).

On-road cycle lanes are also likely to have an effect on the proportion of adults who consider cycling to be a good way to get to work. In a cross sectional study of American cities Dill and Carr (Dill & Carr, 2003) found that each additional mile of bicycle lane per
square mile was associated with a 1% greater level of commuter cycling. Jensen’s before-and-after study of bicycle tracks and lanes in Denmark demonstrated a 5% increase in cycle traffic on the treated streets. This was likely to have resulted from both a mode shift to cycling and from route changes by existing cyclists. I have assumed that if every arterial road included an on-road cycle lane the proportion of people considering cycling to be a good mode for commuting would linearly increase from a baseline of 0.1 to a maximum of 0.4 as the proportion of roads treated increases.

8.2.2. Off-road shared paths

The off-road paths described in the regional cycle network plan include specifically built paths that are not part of the road network and footpaths that have been split into pedestrian and cycle ways with painted markings. They vary greatly in width and quality. An example of a specifically built path in Auckland is shown in Figure 8-4.

![Figure 8-4 Example of an off-road cycle lane in Auckland](image)

Shared footpaths and shared off-road paths have been treated as a single group since estimates of their effect on safety are similar. However, there are qualitative differences in the risks posed by these two facilities. Cyclists are more visible to cars on shared footpaths than off-road, but must cross driveways and side streets (where the risk of collision is high). Both kinds of infrastructure leave cyclists vulnerable when they re-
enter the traffic at intersections and side streets. All existing studies of shared paths suffer from poor design and are limited to cross-sectional surveys of existing cyclists. The road safety manual reports a “best estimate” relative risk of cycle accidents of 1-3.5 (p. 159) but does not clarify whether this includes cyclist only falls, or collisions between cyclists or with pedestrians as well as vehicles. None of the studies reviewed to develop this estimate were adjusted for the volume of cycle or motor vehicle traffic. Reynolds, et al. review a different set of studies from North America. The best designed studies reported in their review were two studies specific to commuting (Aultman-Hall & Hall, 1998; Aultman-Hall & Kaltenecker, 1999). They used surveys to analyse self-reported use of different infrastructure types and self-reported collisions and injuries. Both these studies combined collisions with pedestrians, obstacles, other cyclists and motor vehicles, and neither study was able to account for differences in motor vehicle volumes or speeds. The two studies were undertaken in urban Ottawa and Toronto using the same survey instrument, targeting urban employees and tertiary students. In Ottawa (Aultman-Hall & Hall, 1998) the collision rates per km travelled of mixing with traffic was equivalent to riding on an off-road shared path or footpath, whereas in Toronto (Aultman-Hall & Kaltenecker, 1999) riding on either a footpath or off-road shared path was associated with significantly more collisions (up to 3.7 times more than riding in traffic). In both studies injury rates per km travelled were higher on both sidewalks and off-road shared paths compared with mixing in traffic.

In the simulation model I have therefore included a best estimate relative risk of collision for off-road paths of 1.0 compared with riding in mixed traffic and a slider to allow a range of possibilities up to an increase in risk by 3.5 times.

In keeping with reports from the US (Goldsmith, 1992) and Australia (Garrard, et al., 2008) I have assumed that shared footpaths and off-road shared paths have a greater effect on perception of safety than either on-road non-separated or physically segregated cycle lanes. In their ecological study of 90 US cities, Buehler and Pucher (2011) found that shared paths were less effective than on-road cycle lanes for attracting cyclists. The placement of off-road facilities can require commuter cyclists to take a less direct route to work, and may be more often used by recreational cyclists while commuters take the shortest path on the road network (Aultman-Hall, et al., 1997; Larsen, 2010). I have therefore modelled an effect of off-road paths on the proportion of people who consider cycling to be a good mode for commuting that is weaker than the effect of on-road
facilities. Overall this means off-road paths and on-road lanes have a similar effect on the utility of cycling, in keeping with the recent findings of Kingham, Taylor and Koorey (2011).

In their 90 cities study, Buehler and Pucher (2011) were also able to analyse the dose-response relationship between the provision of cycle lanes or off-road paths and the commute mode share of cycling, while controlling for other factors such as urban density, number of tertiary students, socioeconomic status and price of fuel. The definition of cycle lanes was very broad, including anything from a physically segregated lane to an arrow-indicated space for cyclists (known in the US as a “sharrow”). Their definition of off-road paths was narrower, consisting of shared off-road paths similar to those found in Auckland. The data from this study\(^{37}\) suggests that doubling the number of km of cycle path per capita results in an increase in the cycling commute mode share by 0.05%. In other words, the planned increase in off-road paths in Auckland from 10 to 25km per 100,000 population would increase commuter cycling from about 2% to 2.6%. However, Auckland is less sprawling than most American cities, where less than 30% of people live within 7km of work (Bureau of Transportation Statistics, 2003) and the range of path provision and cycling mode shares in Buehler and Pucher’s study was small. I have modelled that completing the off-road aspects of the cycle network would increase the regional proportion of people who think cycling is a good way to get to work by 0.1, contributing a mode share increase of between 3 and 4%.

8.2.3. Shared bus lanes

By law cyclists can ride in almost all bus lanes in New Zealand (except for bus lanes that are part of the rapid transit network). Some bus lanes are specifically designed to be shared amongst cyclists, powered two wheeled vehicles and buses. These lanes are painted green, have no physical separation from traffic, and vary in width, consistency and intersection treatments. Some are only designated bus lanes during peak times of the day. Examples of existing shared bus lanes are shown in Figure 8-5.

\(^{37}\) Raw data from this study was provided by Ralph Buehler, October 2011
No studies of the effects of bus/bike lanes on safety or the number of cyclists were found in the peer reviewed literature. However, a recent conference paper (Newcombe & Wilson, 2011) reported a controlled before-and-after study in Auckland comparing the injury effects of four different bus lane routes over a five year period. Changing cycle and traffic volumes were measured for some of the routes, but these changes were not formally accounted for in the analysis. In general, the study found no effect of bus lanes on cycle crashes, with a slight increase in crashes at all sites associated with an increase in cycle numbers. A gradient of risk with bus lane width (up to the recommended width of 4.5m) was found. Compared with expected crashes at each site, a bus lane that was 4.5 metres wide had a relative risk of cycle versus vehicle collision of 0.53, while a lane that was only 3m wide had a relative risk of 2.19. In keeping with the results of this study an option was therefore built in to the model to alter the width of bus lanes in the implemented policy, with the default relative risk set at 1.0.

8.3. Arterial separated bicycle lanes (ASBL)

In contrast to the network approach taken in the RCN, the ASBL policy takes a universal approach to cycling infrastructure. This means that the simulation model assumes that every main or arterial road in the urban region has an equal potential to attract commuter cyclists. This approach to cycle commuting has been recommended in the UK following studies of the unexpectedly small effects of network approaches (Wardman, et al., 1997). The designation of arterial roads by traffic volume also indicates that all arterial roads are

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38 Top photo Daniel Newcombe 2010, with permission
highly used routes particularly at peak times. The ASBL policy comprises the development of a physically separated cycle lane on every arterial road in the Auckland region by 2050 (also called cycle tracks in the literature). There are approximately 960km of arterial road in the region. This policy would result in approximately 70km of separated bike lane per 100,000 people for the region. This level of per capita infrastructure is higher than that currently provided in Amsterdam (54km/100,000) and close to Copenhagen levels (79km/100,000) (Pucher & Buehler, 2008). There are no existing examples of physically segregated cycle lanes in Auckland. Figure 8-6 provides an example from Copenhagen.

![Figure 8-6 Arterial separated bicycle lane in Copenhagen, Denmark](image)

As with the other kinds of cycling infrastructure described above, evidence for the safety and mode share effects of physically separated cycle lanes is poor. The *Handbook of Road Safety Measures* (p. 157-158) reviewed 13 studies from Scandinavia, the Netherlands, Germany and the United Kingdom. Most were before-and-after studies not accounting for changes in either cycling or traffic volumes. These studies suggest that separated lanes significantly reduce the risk of cycling injury accidents on road segments between intersections (midways) by 11% (95% CI -13 to -3%), but increase cycle accidents at intersections. Reynolds, et al. (2009) did not review any studies of separated lanes. The Danish before-and-after study described in Section 8.2.1 (S. U. Jensen, 2008)

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39 Alistair Woodward 2011, with permission
reported similar results: that separated lanes reduced cyclist injuries on the midways by 13% but increased them at intersections. Heterogeneity between road treatments allowed Jensen to demonstrate that maintaining parking on the arterial road and the treatment of cyclists at intersection were important factors for reducing cyclist injuries. More recently, Lusk, et al. (2011) reported a controlled cross-sectional study of six roads with and eight roads without one-sided separated bike lanes in Canada. Only injuries on midways were analysed (intersection crashes were excluded) and the analysis was controlled for direct cycle counts and motor vehicle volumes. The overall relative risk of injury on a separated cycle lane compared with cycling on a control street was 0.72 (95% CI 0.6 – 0.85). All the studies examining the effects on safety of separated cycle lanes highlighted the difference in effect of separated lanes between road lengths and intersections and therefore the heightened importance of dealing safely with the re-entry of cyclists into traffic at intersections.

I have therefore modelled the midway effects of the ASBL policy using the point estimate from Lusk as a surrogate for the effect on collisions, with a slider to allow the simulation of the most pessimistic upper bound reported in Jensen (a 10% increase in risk) and the most optimistic lower bound reported by Lusk, et al. (a 40% decrease in risk). All of the effect on injury is mediated by changing the rate of collision rather than any change in the crash injury or fatality ratio.

Jensen’s findings described above highlight that safe treatment of cyclists at intersections is especially important when they are physically segregated during the midway. This includes entrances from side roads onto arterials and the places near signalised intersections or roundabouts where cyclists change from full separation to greater integration with motor vehicle traffic. Three main interventions have been demonstrated to improve safety: interruption of separated cycle lanes before signalised intersections; advanced stop lines and advance bike boxes or reservoirs; and continuing curbed and raised cycle lanes across side roads. The Handbook of Road Safety Measures (p. 160-161) reported two studies of ending segregation before intersections not available in English. The design of these studies was not described. The best estimate reported in the handbook is a significant reduction in cyclist accidents of approximately 30% (95%CI -45% to -12%) when the segregated lane ends with either a marked lane or mixing with traffic well before a signalised intersection. A more recent controlled before-and-after intersection
treatment study in Australia and New Zealand (S. Turner, Singh, Allatt, & Nates, 2011) showed that when coloured cycle lanes led to advanced stop lines or boxes in combination with exclusive vehicle left turning lanes (Figure 8-7), there was a 20% reduction in cyclist crashes. The depth of advance bike boxes was also found to be important, with deeper reservoirs conferring a greater benefit.

In a rare side street study, Gårder, Leden and Pulkkinen (1998) combined before-and-after data, expert opinion and city-wide injury data to analyse the effect of elevating segregated cycle lanes across side street intersections. They concluded that such treatments reduce cyclist accidents by between 10 and 50%.

The simulation model therefore includes best practice intersection treatment as a separate button. The best practice treatment assumes that all arterial separated bicycle lanes are accompanied by marked lanes to advanced bike boxes at signalised intersections, as well as elevation at side streets. When included in the simulation, the intersection treatments enhance the safety effect of arterial separated bike lanes by a further 25% in the policy’s relative risk of fatal and serious injury.

In keeping with the potential balancing loop in the commuter cycling causal loop diagram (B1 in Figure 7-1), and the experience in Europe where a successful mode shift to cycling
has been a result of both investment in infrastructure and making car use less convenient (Pucher & Buehler, 2008), the ASBL policy assumes a minimum possible purchase of extra land to create cycle lanes, and the reallocation of space from driving lanes instead. Most arterial roads in Auckland currently comprise either four vehicle lanes, or two very wide lanes with adequate space on both sides for an on-road cycle lane. Depending on the effectiveness of the cycling infrastructure in achieving mode shift, removing driving lanes could lead to some increase in congestion, or to maintaining current levels of congestion. Transferring space from motor vehicles to cycling ensures that traffic speeds are not increased via significant congestion reduction, and may assist with encouraging a mode shift from car use to cycling.

The studies discussed in Section 8.2.1 indicated that physically separated on-road lanes have a stronger intermediate effect on the perception of cycling safety than marked lanes, but weaker than off-road paths. Jensen’s perception of safety research in Copenhagen (S. U. Jensen, et al., 2007) (illustrated in Figure 8-3) suggests that if every arterial road in the region included a physically separated lane, then about 78% of people would consider cycling to be always or mostly safe. I have used this to model the effect of the ASBL policy, assuming a linear relationship between the proportion of arterial roads treated and the effect on perception of safety.

Since arterial roads by definition are the major roads that carry people to work, I have included an effect of separated bike lanes on the percentage of people who consider cycling is good for the trip to work that is stronger than the effect of marked lanes, linearly increasing the proportion of people considering that cycling is a good mode for commuting from a baseline of 10% to a maximum of 50% when all roads are treated.

8.4. Self explaining local roads (SER)

This intervention for local and collector roads is consistent with the recommendations in Figure 8-1. Controlling the speed and volume of motor vehicle traffic is an established approach to reducing the risk of collision and injury. On residential streets (local roads) reducing speed limits and using physical measures to calm traffic have been demonstrated to be effective at reducing speed and injury accidents (Bunn, et al., 2003; 1996). However, signposting a lower speed limit on its own has a limited effect on drivers’ behaviour (OECD & Ministers, 2006). A 10km/h reduction in the posted speed limit
reduces the average speed by only 3-4km/h (Elvik, et al., 2004; OECD & Ministers, 2006; Ragnoy, 2005). In Auckland, despite urban roads having a speed limit of 50km/h or less, mean free-flowing arterial speeds are consistently above 50km/h. The most recent speed survey reported a mean arterial free-flowing speed of 55km/h and an 85th percentile speed of 59 km/h (W. Jones, 2010).

Research about driver behaviour in different road environments has increased understanding of the factors influencing driving speeds, including those related to the design of the physical environment (Martens, Comte, & Kaptein, 1997). Self explaining roads create a clear road classification that communicates the correct speed for a particular road through a set of unique elements for each road class (Theeuwes & Godthelp, 1995). In the case of local roads, slow speeds are created by aesthetically telling a story to drivers about the use of the street and the likelihood of obstacles or vulnerable road users. Road narrowing, tree planting, street art and wide footpaths all increase the presence of pedestrians and a range of activities on the street. This slows traffic more successfully than relying solely on speed limit signs, especially when this cue is dissonant with the dominant cues provided by the road’s design (Weller, Schlag, Friedel, & Rammin, 2008). The concept of self explaining roads is a significant part of the Sustainable Safety approach to road traffic injury in the Netherlands (Wegman, Dijkstra, & Schermers, 2005; Weijermars & Wegman, 2011). Few studies have demonstrated the specific effects of creating area-wide self explaining roads but the wider evidence related to traffic calming is relevant. The Cochrane systematic review of area-wide traffic calming undertaken by Bunn, et al. (2003) reviewed 22 controlled before- and-after studies reporting the effects on road traffic collisions and injuries of more traditional traffic calming measures such as traffic diversion; street closures to through traffic; and speed humps. They found that such calming measures reduced the risk of road traffic injury compared with control streets by 15%. The effects on mean speed and speed distribution were not reported in the review. A more recent controlled before-and-after study of low speed zones in London (Grundy, 2009), which adjusted for the city’s wider trend of declining road traffic injury, found a larger reduction in road traffic injury (42%).

A single controlled before-and-after study of an area wide self explaining road intervention has been undertaken in Auckland (Charlton, et al., 2010), where 11km of local and collector roads were treated in a single residential area with a high crash rate. Indicative treatments are shown in Figure 8-8.
Figure 8-8 Self explaining road treatments in the Auckland pilot study

Figure 8-9 Distribution of speeds on local and collector roads before (top) and after (bottom) self explaining road treatment (Charlton, et al., 2010)

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40 Top photo reproduced with permission from Hamish Mackie, 2010
Figure 8-9 (above) demonstrates the change in mean speeds and speed distributions for the local and collector roads in the study. The mean speed on treated local roads was reduced from 44 to 30km/h, while control street speeds remained the same.

The policy simulated creates a self explaining local road on every local road that is a through road in the Auckland region by 2051; a total of 1296km of road. The modelled effect on vehicle speed is to reduce the average speed on the region’s local roads by a linear reduction in proportion to the percentage of local roads treated, to a maximum of 15km/h when all roads are treated. The reduction in speed reduces both collisions (by increasing the stopping time) and the collision to injury ratio. The Speed Management report (OECD & Ministers, 2006) estimates that for every 10km reduction in average speed, there is a 60% reduction in collisions. Elvik’s more recent re-analysis (2009b) suggests this may be an overstatement of the effect of reducing the average speed on urban roads, since the initial speeds are lower. In the absence of a clear alternative, I have used the OECD estimate, but acknowledge this may overestimate the benefit.

The SER policy is also likely to have other effects. In the Auckland study, the self explaining roads were found to have varying effects on traffic volume, with an average reduction in volume of 23%. In the cost-benefit analysis of area-wide traffic calming performed by Elvik, et al. in the Handbook of Road Safety Measures (p. 408), a 25% reduction in traffic volumes on the treated local streets was assumed. I have therefore included a linear reduction in the proportion of vehicles on through local streets at peak time proportional to the percentage of treated streets, up to a maximum of 25%. The proportion of time spent on local roads by cyclists in their trip to work is also likely to increase as traffic speeds on those roads decline. Although there is no specific data in the literature to support this, discussions with cycling researchers and decision-makers led me to include this effect. If all local roads were treated, then the model assumes cyclists would increase the time they spend on local roads from 50 to 70%.

The effects of self explaining roads on determinants of mode share have not been studied. Modest effects on cycling sense of safety and the proportion of people who consider cycling to be good for work are included in the model; with a stronger negative effect on the perception of car use convenience. These effects are summarised in Table 8-3.

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41 At BECA Infrastructure Ltd and Cycling and Walking, Auckland Transport
Influence on mode share | Effect of SER policy
--- | ---
Cycling sense of safety | +10%
Cycling good for work | +10%
Light vehicle “hassle-free” | -30%

Table 8-3 The effect of self explaining roads on mode share influences

Since its strongest effect is to reduce the utility of light vehicle, the SER policy increases the commute mode share of all other modes (not just cycling).

Although the model captures the SER outcomes from reducing light vehicle use well, there are other outcomes related to increasing walking and public transport that are not modelled. These include improved pedestrian safety on local roads; reductions in all-cause mortality due to walking physical activity; and the competing effects of improved air quality on residential streets versus increased public transport PM$_{10}$ emissions. Likewise, only the fuel cost savings for cyclists are included, which underestimates the fuel cost savings from the mode shift to walking and public transport in this scenario.

### 8.5. Policy implementation

#### 8.5.1. Pattern of implementation

No detailed implementation plan is available for the RCN and I have not developed a detailed plan for the universal policies. Instead, the implementation of all policies is simulated by an S-shaped cumulative frequency curve, with a gradual build up in intensity to a maximum in the middle of the implementation period, followed by a decline in intensity towards 100% implementation. This is demonstrated by the example in Figure 8-10.
The shape of the implementation curve affects intervention costs because of escalation in estimates of future construction costs. It also affects the magnitude of public health outcomes because of changes in the shape of business-as-usual outcome curves over time and also because the speed of implementation determines how rapidly the safety in numbers mode share threshold is reached for cyclist injury outcomes.

### 8.5.2. Baseline intervention costs

Costs per km for all the interventions have been estimated from data provided by the staff at Auckland Transport. A range of estimates were supplied for three kinds of infrastructure planned in the RCN policy and I have used the best estimate provided for each range. Since no data were available to estimate the cost of arterial separated bicycle lanes, I have used the upper bound of the estimate for shared bus-bike lanes. This may be an overestimate since bus-bike lanes are more likely to require road widening and land purchase. I have assumed that the cost of the best practice intersection treatments would be included in the ASBL per km estimate. For the self explaining roads policy I have used the cost per km of the Auckland pilot provided by the authors of the paper reporting this study (H.W. Mackie, personal communication, August 20, 2011). This almost certainly overestimates the per km cost of treating all local roads. As the pilot is scaled up, the intervention would become usual practice and there would be competition between construction companies for project tenders. Both these factors would significantly lower

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42 Data supplied by Brian Horspool, Regional Walking and Cycling Coordinator, Auckland Transport, March 2011
the per km cost of this intervention. All costs per km used in the model are in 2011 New Zealand dollars and are summarised in Table 8-4.

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Cost per km range (best estimate)</th>
<th>Cost per km modelled</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-road marked cycle lane (2 sides)</td>
<td>$5-40,000 ($15,000)</td>
<td>$15,000</td>
</tr>
<tr>
<td>Shared bus-bike lane (2 sides)</td>
<td>$50-200,000 ($100,000)</td>
<td>$100,000</td>
</tr>
<tr>
<td>Off-road shared path</td>
<td>$75-400,000 ($150,000)</td>
<td>$150,000</td>
</tr>
<tr>
<td>On-road separated lane + intersection treatment</td>
<td>None supplied</td>
<td>$200,000</td>
</tr>
<tr>
<td>Self explaining local road</td>
<td>$300,000</td>
<td>$300,000</td>
</tr>
</tbody>
</table>

Table 8-4 Estimated costs per km of policy interventions (adapted from estimated costs of completing the planned Regional Cycle Network, and data supplied by the authors of the SER pilot study)

8.5.3. Cost escalation

All transport projects submitted to the New Zealand Transport Agency for funding are subject to price escalation when planned into the future, to account for the rising costs of construction. This is generally set at twice the expected rate of inflation, and a rate of 3% is currently recommended by the New Zealand Transport Agency and Auckland Transport (I. Melsom, personal communication, September 12, 2011).

8.6. Policy simulations

All the policy simulations run from 1991 to 2051. The outputs from 1991 to 2011 were used to compare the simulation model with historical data. All policies are implemented in 2012. The RCN policy is completed by 2040, whereas the ASBL and SER interventions are completed in 2051. Future outcomes are not discounted. The policy simulations can be run using the model included on the accompanying CD.

The simulation interface shown below demonstrates the way users can customise policy options and assumptions, as well as how outcomes are visualised both graphically and in summary form (Figure 8-11).
In the following policy simulation results, comparative model output graphs are labelled by scenario in the following order:

1. Business-as-usual (no investment in cycling, BAU)
2. Regional cycle network mandated by the ARLTS 2010 (RCN)
3. Arterial separated cycle lanes with best practice intersections (ASBL)
4. Self explaining local roads (SER)
5. Combined universal approach (Policies 3 and 4 together)

The results of scenario runs of the model are described below. Because of the uncertainties in the model and its reflective (rather than predictive) purpose, I have deliberately avoided reporting specific numerical results. Graphical outputs therefore lack gridlines, but include y-axis scales to indicate the magnitude of results. Outcomes are discussed in terms of the direction and magnitude of change, behavioural characteristics and comparative differences between policy options.
8.6.1. Mode share

The business-as-usual scenario projects walking and cycling to remain at current levels, while modest improvements in public transport result in some increase in the public transport mode share, with a concomitant slight decrease in light vehicle mode share (Figure 8-12).

All other scenarios are behaviourally similar and increase the mode share of cycling, achieving mode shares in the tens, as demonstrated by Figure 8-13. No policy achieves a cycle mode share greater than 50%. The RCN and SER policies (2 and 4) have very similar effects on mode share (Figure 8-13), but because the main effect of the SER policy is to make light vehicle commuting less convenient, it affects all modes (Figure 8-14). If we assume that the Auckland Regional Land Transport Strategy’s 34% target for walking and cycling could be split equally between the two modes, then cycling policies need to raise the mode share for all trips above 17%, and policies 3 and 5 are most likely to achieve this.
Chapter 8 – Policy simulations

Figure 8-13 Projected cycle commuting mode share under all scenarios

Figure 8-14 Projected mode share for all modes under scenario 3 (SER)

Figure 8-15 Projected commute mode share for all modes under scenario 5
The combined ASBL and SER policy 5 has a considerably stronger effect that is greater than the sum of the two policies separately. The effect of policy 5 on overall mode share is demonstrated above (Figure 8-15).

8.6.2. Injury and perception of safety

All scenarios result in an increase in the number of injuries caused by collisions between commuter cyclists and motor vehicles, including scenario 1 (Figure 8-16). With no investment in cycling infrastructure, it is likely that a small proportion of commuters will continue to cycle, similar to the proportion currently cycling (approximately 1%). This sector of the population is relatively insensitive to the risk of cycling, and their number will increase as the population grows. The annual order of magnitude of serious injuries for scenario 1 is in the tens, with fatalities continuing to be in the units, whereas all other scenarios result in annual serious injuries in the hundreds, with annual fatalities in the tens. Scenarios 2, 3 and 4 are behaviourally similar, with increasing injuries over time, whereas scenario 5 (ASBL and SER) is behaviourally slightly different, with an earlier, sharper peak in injuries occurring as the rapid increase in cyclist numbers leads to an early activation of a safety in numbers effect.

Figure 8-16 Annual commuter cyclist serious and fatal injuries due to collisions with light vehicles (all scenarios: 1 – BAU, 2 – RCN, 3 – ASBL, 4 – SER, 5 – ASBL + SER)
Scenarios 1 and 2 both result in a steady increase in the rate of cyclist injury. Under a business-as-usual scenario this is explained by a growing number of vehicles due to population growth. The effects of the planned RCN on mode share and safety appear to be too weak to counter this pattern of growth. In contrast, scenarios 3 to 5 reduce the rate of injury due to collisions with light vehicles (Figure 8-17). Scenario 5 reduces commuter cycling injury rates to a greater degree than the sum of its component parts. Although scenario 4 (SER) does not have a large effect on cycle mode share, it has a strong effect on the cyclist versus light vehicle injury rate due to the shift in the balance of light vehicles towards arterial roads and cyclists towards local roads in the trip to work. All scenarios that reduce motor vehicle mode share will also reduce road traffic injuries for motor vehicle drivers and passengers. This affect has not been simulated but would only
partly offset the increase in cyclist injuries. Under the default assumptions included in the model none of the scenarios alone would assist the Auckland Council in meeting its road traffic injury targets. Further policy interventions may be needed to improve the safety of cyclists (such as education and reducing vehicle speeds on arterial roads).

The planned RCN is unlikely to achieve the perception of safety policy target of 80% of people considering cycling always or mostly safe (Figure 8-18). The only policy that is likely to reach this target is policy 5 due to the powerful combined effect of arterial separated lanes and traffic calming on perception of safety.

### 8.6.3. Air pollution outcomes

All of the air pollution outcomes modelled (mortality, hospitalisations, cancer, COPD hospitalisations and restricted activity days) demonstrate the same pattern of behaviour over time (shown for all-cause mortality in Figure 8-19).

The behaviour for all these outcomes demonstrates two turning points. The first is likely to have already occurred, where technical innovation to reduce light vehicle PM$_{10}$ emissions in response to air quality standards is reducing emissions from the light vehicle fleet faster than the growth in light vehicle km travelled, leading to a steady reduction in the burden of disease attributable to the commuting light vehicle fleet. This reduction is eventually projected to slow until the growth in light vehicle km travelled again overtakes it and emissions begin to increase again. The timing of the second turning point is not
known and depends on assumptions about the proportion of emissions that can ultimately be avoided through vehicle technology. The magnitude of these expected business-as-usual trends means that policies reducing light vehicle km travelled by increasing the cycling mode share make only modest differences to air pollution outcomes attributable to the commuting light vehicle fleet. All scenarios demonstrate the same behavioural patterns, with the order of magnitude of savings indicated in Table 8-5.

<table>
<thead>
<tr>
<th>Air pollution outcomes attributed to commuting $PM_{10}$</th>
<th>Magnitude of annual savings for scenarios 2-5 by 2051</th>
</tr>
</thead>
<tbody>
<tr>
<td>All-cause mortality</td>
<td>Less than 10</td>
</tr>
<tr>
<td>Hospitalisations</td>
<td>Less than 10</td>
</tr>
<tr>
<td>COPD incidence</td>
<td>Less than 10</td>
</tr>
<tr>
<td>Cancer incidence</td>
<td>Less than 1</td>
</tr>
<tr>
<td>Restricted activity days</td>
<td>In the hundreds (scenario 2)</td>
</tr>
<tr>
<td></td>
<td>In the thousands (scenarios 3-5)</td>
</tr>
</tbody>
</table>

Table 8-5 Air pollution outcomes for scenarios for all investments in cycling infrastructure

Scenario 5 has the greatest effect on all air pollution outcomes. Scenario 4 (SER policy) has a greater effect than Scenario 3 (ASBL policy) as it reduces light vehicle km travelled to a greater extent by increasing all other modes.

8.6.4. Physical activity

Annual all-cause mortality savings, due to changes in cycle commuting physical activity, range from the tens to the hundreds under all scenarios (Figure 8-20). The business-as-usual scenario demonstrates the competing effects of a growing population and other influences on declining all-cause mortality (such as reductions in smoking prevalence), resulting in an increase in annual deaths that does not keep pace with population growth.
Scenarios 2 and 4 (RCN and SER) achieve an almost identical small annual all-cause mortality saving in the tens. Scenario 3 (ASBL) has a stronger effect with annual savings increasing from the tens to the hundreds over the simulation period. Scenario 5 has the strongest effect, achieving all-cause mortality savings in the hundreds from early in the simulation period.

The scenarios assume that the increase in commuter cycling occurs evenly by gender, age group and ethnicity within the commuting population. Because of this assumption, the greatest gains in terms of numbers of lives saved occurs in non-Māori/non-Pacific men aged 45-64. However, prioritising populations with the highest existing mortality rates would maximise the health equity gain. In practice, this would involve prioritising infrastructure implementation in neighbourhoods with the highest proportions of Māori and Pacific men and women aged 25-64.

8.6.5. Greenhouse gas emissions

Figure 8-21 shows the effects of all scenarios on per capita greenhouse gas equivalent emissions for the whole Auckland population attributable to commuting.
Similar to the air pollution outcomes, the behaviour of modelled greenhouse gas emissions suggests that the contribution of the commuting light vehicle fleet may have already peaked. Even under scenario 1, per capita CO$_{2eq}$ emissions are expected to decline almost to 1991 levels by 2051. Scenario 5 is likely to make the largest contribution to meeting the overall domestic transport target to halve per capita emissions by 50% of 2006 levels by 2040. Under the default assumptions scenario 5 halves the commuting per capita contribution, which would address the commuting contribution to overall transport emissions. Extrapolating the contribution of these reductions to overall transport emissions would require further analysis using the VEPM 5.0 model.

8.6.6. Fuel cost savings

There are projected fuel cost savings from commuter cycling for all scenarios, increasing over time because of increasing numbers of cyclists combined with projected increases in the cost of petrol and diesel. Taking these expected trends into account, as well as the changing ratio of diesel: petrol engines in the light vehicle fleet and increasing fuel efficiency, Figure 8-22 shows the increase in per cyclist annual fuel cost savings over time. This increase assumes no change in the average distance travelled to work over time. The simulation suggests that annual fuel cost savings for the average trip to work are likely to remain in the hundreds of NZ dollars. Figure 8-23 demonstrates the total fuel cost savings simulated for all scenarios in 2008 million dollars.
The business-as-usual scenario results in savings in the millions of dollars by 2051, scenarios 2 and 4 (RCN and SER) achieve savings in the tens of millions, while scenarios 3 and 5 (ASBL and combined) achieve hundreds of millions of dollars of annual savings. Scenario 5 achieves the largest savings because of its impact on cycling mode share.

Despite the expected increase in fuel prices and the large population level savings seen in some scenarios, the cost of an average trip to work remains surprisingly small and stable due to projected fuel efficiency trends. A 6km trip in 2012 at average fuel efficiency costs approximately $1.70 and this is expected to rise to $1.95 by 2040. This suggests that reliance on the increasing cost of fuel alone to change individual cost-benefit decisions is unlikely to achieve a significant commuting mode shift.
8.6.7. Policy costs

The costs of policies 2 to 5 are summarised in Table 8-6 under three different escalation scenarios. The infrastructure cost of regional cycle network is reasonably low, while the region-wide changes associated with scenario 5 are the most expensive.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total cost to 2051</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No escalation</td>
</tr>
<tr>
<td>2 RCN</td>
<td>45.56</td>
</tr>
<tr>
<td>3 ASBL</td>
<td>250.97</td>
</tr>
<tr>
<td>4 SER</td>
<td>379.08</td>
</tr>
<tr>
<td>5 ASBL + SER</td>
<td>630.04</td>
</tr>
</tbody>
</table>

Table 8-6 Total cost of all scenarios to 2051 in millions of 2011 NZ dollars with different rates of escalation

The mid-range escalation estimates demonstrate that spending approximately $3.8 billion dollars over the next 40 years (an average of $95 million per year) would be needed to transform Auckland’s local and arterial roads in a consistent manner. Because the implementation is modelled as an s-shaped cumulative frequency curve, this would involve spending about $90 million annually for the first three years and gradually increasing the annual investment after this to a maximum of $236 million between 2021 and 2027 then gradually reducing the annual spend again to 2051. The current funding plan for 2012-2015 (P. Clark, 2011) includes a total projected investment in transport for the Auckland region of $2.87 billion. Of this 0.9% ($27 million) is expected to be invested annually in walking and cycling. This would need to increase to 3% of the total budget annually to commence the investment in policy 5.

8.7. Summary of costs and benefits

Table 8-7 provides indicative cumulative costs and benefits of scenarios other than business-as-usual to 2051, using the best estimates from the model. Including such a table may appear to be predicting effects rather than reflecting on behaviour, direction and magnitude of outcomes. However, I have used rounded figures to provide some indication of the relative magnitudes of outcomes and comparative benefit-cost ratios for the four policy interventions. Factors exogenous to the cycle commuting feedback loops (Figure
7-1), such as weather, topography and education, are likely to modify the effect sizes in the table but not the shape and direction of change over time.

As stipulated in the NZTA Economic Evaluation Manual (New Zealand Transport Agency, 2010) I have used non-escalated infrastructure costs when comparing the costs and benefits. Where possible I have monetised benefits and costs using the values provided in this manual. I have provided non-discounted values.

The Economic Evaluation Manual (New Zealand Transport Agency, 2010) includes financial costs for a cycling fatal injury accident ($3.1 million), a serious cycling injury accident ($0.325 million) and a metric ton of greenhouse gas emissions ($40). The cost estimate for a cycling fatal injury has also been used to value mortality savings from increased cycle commuting physical activity.

The cost of premature mortality ($0.75 million); cardiovascular and respiratory hospitalisation (weighted average $0.003 million); COPD hospitalisation ($0.075 million); cancer ($0.75 million) and restricted activity days ($98 per day) attributable to air pollution are taken from the 2010 HAPiNZ update for Auckland (Kuschel & Mahon, 2010).

In calculating the Benefit-Cost Ratio (BCR) I have used method in the NZTA Economic Evaluation Manual (2010), which is to sum the net public health benefits and divide those by the infrastructure cost.
Table 8-7 demonstrates that benefits would be greater than costs for all the modelled investments in cycling infrastructure. However, there are large differences in the order of magnitude of net benefits. The regional cycle network would likely result in hundreds of millions of dollars in benefits, while scenarios 3 (ASBL) and 4 (SER) would each result in billions of dollars of benefit through different pathways. Scenario 5 (combined ASBL and SER) would likely result in tens of billions of dollars of benefit. The BCRs for all the investments are much higher than normally reported for transport projects. For scenarios 1, 2 and 5 the BCRs are an order of magnitude higher than typically reported, for example the current proposal to build an inner city rail tunnel has a calculated BCR of 1.1-2.3.
(Ministry of Transport, The Treasury, & NZ Transport Agency, 2011), while the proposal to extend part of Auckland’s motorway north has a BCR of between 0.8 and 2.0 (NZ Transport Agency, 2010). This is likely to be because BCR calculations for all projects tend to poorly estimate the public health and mode shift benefits, but also because active transport projects are relatively cheap, with much greater benefits to public health than road or public transport infrastructure projects.

A range of benefits that were identified in the literature have not yet been simulated in the model. The reduction in light vehicle crashes resulting from a reduction in peak time light vehicle travel has not yet been modelled. This would partially offset the increased cost of cycling injuries. Currently, only the mortality savings of increased commuter cycling-related physical activity are counted, but there would also be significant morbidity savings under all scenarios, such as reduced costs to society of high blood pressure, diabetes, non-fatal cardiovascular disease and depression. Other benefits not quantified include improved trip time reliability, reduced stress, improved water quality, and reductions in the need for arterial road widening and car park construction. All scenarios are likely to have health and social equity benefits (even without prioritising interventions by social group), through reductions in transport-sensitive unemployment (people who are unable to access a job because of lack of transport) as well as through the proportionate benefits of fuel cost savings by household deprivation. Prioritisation of cycling infrastructure to high deprivation neighbourhoods would significantly increase these equity benefits because of socioeconomic gradients and ethnic inequities in road traffic injury, air pollution mortality and all-cause mortality sensitive to changes in levels of physical activity.

8.8. Sensitivity analysis

The method applied to the sensitivity analysis was described in Section 5.9 and a complete report of the analysis can be found in Appendix D. During the sensitivity testing I was interested in three specific categories of sensitivity are described. Firstly, I wished to identify assumptions that caused changes in the behaviour of outcomes over a plausible range of testing. A secondary goal was to identify assumptions for which testing resulted in changes in the order of magnitude of outcomes. Thirdly, variability in the value of outcomes (within the same order of magnitude) was expected given the uncertainty in data sources and the reflective (as opposed to predictive) purpose of the model. The range
of cost estimates provided by Auckland Transport was tested in the analysis. In addition, all the assumptions about the effects of policies on safety and the determinants of mode share were tested in the against injury and mode share outcomes.

The model was behaviourally stable to all the policy variables tested.

Analysis over the full range of average annual costs for scenarios 2 (RCN) and 5 (ASBL + SER) led to changes in the order of magnitude of annual costs. The RCN annual cost ranged from $4.4-24.7 and policy 5 annual costs ranged from $39-116 million. All other total and annual costs were order-of-magnitude stable.

Worst and best case scenarios were simulated for the injury outcomes of each scenario, followed by a Monte Carlo approach for policy variables affecting the injury outcomes. A Monte Carlo approach was used to randomly sample from distributions of variables determining mode share to provide a range for the mode share outcomes of each scenario. The results of these analyses are summarised in Table 8-8.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Scenario 2 (RCN)</th>
<th>Scenario 3 (ASBL)</th>
<th>Scenario 4 (SER)</th>
<th>Scenario 5 (ASBL + SER)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycling mode share</td>
<td>0.02-0.08</td>
<td>0.1-0.24</td>
<td>0.02-0.16</td>
<td>0.2-0.52</td>
</tr>
<tr>
<td>Annual serious and fatal injuries:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Worst and best case scenarios</td>
<td>310-500</td>
<td>500-960</td>
<td>111-212</td>
<td>223-1177</td>
</tr>
<tr>
<td>Monte Carlo analysis</td>
<td>200-335</td>
<td>233-563</td>
<td>N/A</td>
<td>201-755</td>
</tr>
</tbody>
</table>

Table 8-8 Range of mode share and annual injury outcomes for all scenarios from the sensitivity analysis of policy assumptions

It can be seen that cycling mode share is order-of-magnitude sensitive to assumptions under scenarios 3 and 4. Some overlap between scenarios is also evident from the Monte Carlo analysis (Figure 8-24), but the model retains its ability to distinguish between scenarios 2, 3 and 5.
Annual injury outcomes exhibit less overlap than the mode share outcomes overall, although a greater degree of overlap was again seen in the injury ranges for scenarios 3 and 5.

Assumptions about safety in numbers and variables influencing the effect of commuter cycling on all-cause mortality were tested separately. Changing the threshold for the safety in numbers effect to 5% cycling mode share did not alter the behaviour or order of magnitude of injury outcomes. However, simulating the power function from Jacobsen with no threshold changed the behaviour of injury outcomes. Simulating the range of relative risks of all-cause mortality for commuter cycling (using a Monte Carlo approach with the confidence intervals in the literature) altered the order of magnitude of all-cause mortality savings for all scenarios and disabled the ability of the model to distinguish between any of the active interventions. Monte Carlo simulation of a plausible range of lead times for physical activity benefits to accrue led to order-of-magnitude differences for scenarios 2 and 5, while only retaining the ability of the model to distinguish between scenario 2 and 5.

8.9. Policy insights from the simulation model

Simulating the cycling sector of the commuting SD model under a range of policy scenarios has led to a number of insights of value for policy makers. Although best estimates suggest that all the infrastructure investment scenarios have a positive effect on
cycling mode share and therefore overall public health outcomes, the benefit to cost ratio of the planned regional cycle network is marginal compared with the other scenarios.

The simulation model demonstrates that even a business-as-usual scenario will contribute to some of the targets in the RLTS, taking into account expected modest increases in public transport use, and more significant improvements in fuel efficiency and light vehicle emissions. The reduction in particulate emissions from the light vehicle fleet expected by the VEPM 5.0 for Auckland results will mean that the contribution of the light vehicle fleet to the future burden of disease from air pollution may be surprisingly small.

The target to increase active transport combines walking and cycling. Splitting the target evenly gives a cycling mode share target of 17% by 2040. To approach this target, the simulations suggest a more concerted effort will be needed than the planned investment. The consistent best practice approach to arterial roads, by re-allocating existing road space to ensure that vehicle speeds do not increase, may achieve this target on its own. This is due to the effectiveness of on-road segregation for improving both actual and perceived cycling safety.

Scenario 5 is most likely to achieve all except the injury target, and is the only scenario likely to meet the perception of safety target. The kind of universal transformation represented by this scenario is similar to the approach taken in cities like Amsterdam and Copenhagen, and over a similar period of time (Pucher & Buehler, 2008). However, the resulting commute mode share may be optimistic since the model is simulating the effects of policies to increase cycling in the absence of likely policies to change the utility of other modes (such as the programmes of investment in road building and public transport signalled in regional and national policies).

When people consider the marginal cost of travelling to work by car, the direct and evident cost of fuel tends to be the only cost counted, while “sunk” costs such as insurance, the cost of long-term parking, maintenance and the cost of car purchase tend to be ignored (Spurling, 2010). Simulating the projected cost of fuel together with expected improvements in fuel efficiency demonstrates that the individual cost-benefit analysis of light vehicle commuting costs may not be a significant factor in changing commute mode share.
The simulations suggest a mismatch between targets in the RLTS. The target to reduce vehicle trip growth may be met by doing nothing, and should therefore be more ambitious. On the other hand, the simulations suggest that the perception of cycling safety target will be very difficult to achieve, and that doing so would result in a much higher cycle mode share than targeted. Under the safety in numbers assumption simulated here, higher cycle mode shares will increase the crude number of cyclist fatalities and serious injuries. Without other efforts to improve cyclist safety this may hamper the achievement of the road safety targets.

Assumptions about a safety in numbers effect for cycling have a large influence on the injury cost associated with increasing cycling under all scenarios. Although Auckland data suggest that a safety in numbers effect is not evident at such low levels of cycling, in keeping with a threshold (or a reverse s-shaped curve) it is not clear where the threshold or turning point might be. The simulations using a 10% mode share threshold are likely to be pessimistic. If there is a threshold, the simulations suggest that the faster that threshold is reached (through rapid investment in effective policies), the earlier the injury curve flattens, and the lower the injury cost of increasing the cycle commuting mode share. Any increase in other transport and recreational cycling accompanying best practice infrastructure investments would assist in reaching the threshold and strengthen the safety in numbers feedback loop.

8.10. Summary

This chapter has described the further development of the commuter cycling simulation model to allow the simulation of a range of policies aimed at increasing commuter cycling, including the cycling investment currently proposed in the Auckland Regional Land Transport Strategy, as well as three best practice scenarios for arterial and local roads. Using the best evidence available for the effectiveness of different kinds of intervention, the simulated scenarios have demonstrated the most likely shape, direction and comparative magnitude of change over time to commute mode share and a range of public health outcomes. The simulation model can be used to identify the level and type of investment that may be needed to reach strategic transport targets. The model is behaviourally robust and magnitude stable to most variables. Under a plausible range of assumptions it enables the distinction between business-as-usual and three of the four policies tested. The distinction between the Regional Cycle Network and the self
explaining roads policy is lost when these ranges are tested. A further exception is the magnitude of all-cause mortality outcomes due to changes in physical activity.

In keeping with the experience of cities that have achieved high levels of transport cycling, a consistent universal approach to the road network involving on-road cycle lanes that are physically segregated, best practice intersections, and slowing vehicle traffic will be needed to reach these targets. The wide range of effects on safety strongly suggests that to achieve safety benefits cycling infrastructure needs to be built to a consistently high standard. Such interventions will also have benefits that have not been quantified here, by increasing levels of cycling for other purposes, as well as increasing the mode share for walking and public transport while making local roads safer for all age groups.

The next and final chapter brings together the findings from the thesis and in it I reflect on the experience of undertaking an SD modelling process for urban transport policy. I also briefly report preliminary feedback from policy stakeholders about the modelling approach and the usefulness of the simulation model.
Chapter 9. Discussion

The thesis had four aims:

1. To develop a comprehensive conceptual model of the trip to work and public health that synthesises knowledge from epidemiology, communities and policy makers

2. To develop a commuting and public health simulation model that could quantify a range of outcomes for some particular policy options

3. To use this model to identify effective policy levers for intervening in commuting patterns to improve public health outcomes

4. To test the utility of the modelling methodology for integrating public health outcomes in a more participatory approach to transport policy making

In this chapter I discuss how these aims have been met. Firstly, the findings of the research are summarised and the methodology is critically discussed. Secondly, I compare the methodology and results of this research with previous relevant studies and discuss the implications of the research for policy. Thirdly, I identify significant knowledge gaps and methodological questions, and recommend future research directions.

9.1. Summary of the main findings

An ecosystem health approach to public health was the foundation of the research, integrating physical and mental health with environmental sustainability and social equity. This model guided the review of the literature and the methodology.

The commuting and health literature review covered studies from a wide range of academic disciplines including epidemiology; geography; transport engineering; psychology and sociology; and ecology. Many complex connections between commuting and public health were identified, covering all the aspects of public health described by the two models used (Hancock’s ecosystem health model and Durie’s Te Pae Mahutonga). The review demonstrated that a shift is needed from the car-dominant patterns of commuting that characterise most high income cities if public health outcomes
are to be improved and health, equity and sustainability objectives are to be better aligned. The complexity of the links identified suggested the need for new methods of transport decision-making that are able to integrate disparate knowledge, engage a range of stakeholders and address tensions and trade-offs between desired goals. This need has also been identified in the development of “sustainable” transport policy – which includes goals for improving environmental sustainability, equity and public health.

The OECD sustainable transport principles were used to analyse transport policy developments in Auckland and New Zealand. The analysis demonstrated significant shifts in transport policy over the past decade towards the OECD principles. However, a number of reasons were identified for the failure to achieve strategic public health goals. These include: the lack of modelling approaches that can successfully synthesise the required knowledge for backcasting from goals to the policies required; limited opportunities for communities to contribute to regional and national transport decision-making; and a heavy focus on changing the behaviour of individuals through programmes such as workplace travel plans.

The methodological discussion identified system dynamics (SD) modelling as a promising method for addressing this failure. A number of studies involving a range of stakeholders in participatory group learning and decision-making processes suggested that SD modelling could be used to improve participation in transport policy-making. The main part of the thesis therefore tested the potential of SD modelling to improve the public health outcomes of transport policy particularly focusing on commuting in Auckland. An SD modelling process was designed to synthesise local knowledge about commuting and public health into a set of qualitative feedback loops (causal loop diagrams); followed by the development of a regional simulation model to test specific policies aimed at intervening in the trip to work.

Eight qualitative model sectors resulted from the qualitative interviews, workshops and meetings. The overlap between stakeholder understandings of commuting and public health and the themes identified by the literature review was very high, although priorities differed. Stakeholders involved in this research placed the greatest emphasis on aspects of time management, stress and family responsibilities, followed by safety, whereas researchers and public health advocates have tended to focus the greatest effort on addressing injury and air quality. Stakeholders also privileged the structural influences on
commuting (such as urban design and transport infrastructure) over behavioural influences (such as personal choice or culture). The working version of the qualitative model comprises the following high level sectors including 19 reinforcing and 2 balancing feedback loops:

1. Pedestrian and cyclist injury
2. Relative attractiveness of public transport
3. Neighbourhood sense of safety from crime
4. Time pressure and accessibility of employment
5. Workplace support
6. Participation and leadership in transport planning
7. Environmental and cultural wellbeing
8. “Car culture” and social wellbeing

A regional cycling simulation model was then developed, incorporating the feedback loops about cycling from the qualitative work as well as exogenous public health outcomes. Cyclist injuries, fuel-only financial savings, air quality outcomes, greenhouse gas emissions and mortality savings due to cycle commuting physical activity were simulated. Five policy options were able to be compared for their ability to meet quantified policy targets and maximise net public health benefits. The five policies tested were: (1) no further investment in cycling (BAU); (2) the planned Regional Cycle Network (RCN); two region-wide best practice policies – (3) segregated bicycle lanes on all the region’s arterial roads (ASBL) and (4) region-wide self explaining local roads (SER); (5) a region-wide transformation combining the arterial and local best practice approaches. The impacts of all policies were simulated over 30 to 40 years.

Under the best estimate assumptions, all the active interventions had overall benefits to public health, although there were order-of-magnitude differences in public health savings between the policies. Scenarios 2 and 4 were most similar in their effects on commuter cycling and cycling-specific outcomes (increasing the cycling mode share from 1% to between 2 and 8% for the RCN and between 2 and 16% for the SER). Self-explaining local roads are likely to have a multi-modal effect, increasing walking, cycling and public transport. By making local roads more attractive to cyclists, the SER policy would also likely change the routes cyclists use to commute. The net benefit for the SER policy was therefore higher (about $1.8 billion dollars of benefit by 2040 compared with
The ASBL policy alone resulted in a higher cycling mode share by 2051 (between 10 and 24%) but with a cost in terms of injury (under adapted safety in numbers assumptions) despite making cycling significantly safer on arterial roads. The injury cost, combined with the increased infrastructure cost resulted in a lower BCR (about 11) for this policy than the RCN (BCR of 18) under default safety in numbers assumptions, despite the net benefit of the ASBL policy being more than three times as high. Policy 5 significantly strengthened the important reinforcing loops in the commuter cycling model (safety in numbers, reduced cars, lower speeds, improved infrastructure safety and normality of cycling), resulting in the possibility of a cycling commute mode share of between 20 and 50% and a BCR of about 22 under the default assumptions. The simulation model was able to demonstrate the significant public health benefits of active transport projects that are not usually able to be accounted for in traditional cost benefit analyses. This explains the high BCRs.

The public health costs and benefits are dominated by the cost of injuries and the all-cause mortality benefits of cycling physical activity. Compared with these, infrastructure costs and other benefits are small. Overall savings range from the hundreds of millions of NZ dollars (RCN) to the tens of billions of NZ dollars (scenario 5). Scenario 5 was the only policy option likely to assist the council in meeting its strategic goals for cycling and greenhouse gas emissions reductions. Under the best estimate assumptions (particularly the 10% threshold for the safety in numbers effect) none of the scenarios alone would assist the council in meeting its goal to reduce road traffic injuries.

All scenarios would have a range of other benefits that have not been quantified in the model thus far, including improvements in water quality, workforce productivity (through a healthier workforce), reduced morbidity associated with physical inactivity and reduced stress. In addition, the SER policy would be likely to enhance neighbourhood social connection and sense of safety by increasing the presence of pedestrians on local streets and improving neighbourhood aesthetics. Benefits for health and social equity would also result from all the policies because cycling is an affordable mode of commuting that would reduce transport-sensitive unemployment and provide financial savings for poorer households who are currently reliant on car commuting. Prioritising infrastructure investments in low income neighbourhoods and routes to work would enhance these social and health equity benefits.
The model was able to demonstrate the comparative shape, magnitude and direction of change for the different policies over time, accounting for expected business-as-usual trends in population, the light vehicle fleet, fuel costs, all-cause mortality and public transport improvement. In addition, the model was able to show that achieving scenario 5 would involve a relatively small investment over the next 40 years, starting at approximately 3% of the regional transport budget annually.

The formal validation and sensitivity testing of the cycle commuting simulation model demonstrated that the behaviour of outcomes over time were stable to extreme variation in model variables. Injury outcomes in the model were behaviourally sensitive to extreme assumptions about safety in numbers. Air pollution outcomes and greenhouse gas emissions were behaviourally sensitive to changes in the VEPM 5.0 projected improvements in the light vehicle fleet.

Sensitivity testing of the policy outcomes was achieved using a combination of extreme values testing and Monte Carlo analysis. Under the Monte Carlo analysis the simulation model lost the ability to distinguish between the cycling mode share effects of the RCN and SER policies, while retaining the ability to distinguish between policies 2, 3 and 5. In a worst case scenario of safety effects, the RCN would result in a significant increase in the cyclist injury rate. This is because the combination of components has the potential to make cycling more dangerous, and because this policy fails to achieve the level of mode shift to cycling necessary to counter the growth in light vehicles and reach the postulated threshold for a safety in numbers effect. On the other hand, policies 4 (SER) and 5 (ASBL + SER) reduce the cycling injury rate even under worst case scenario testing.

9.2. Strengths and weaknesses of the research

9.2.1. What this research adds

This is the first time SD modelling has been used to integrate a wide range of public health outcomes of transport policy. SD modelling represents an advance on prevailing methods for considering public health in urban planning (such as Health Impact Assessment) since it enables considerations to move beyond draft policy options to start with problematic trends. The process used in this research involved group learning about the relevant dynamics in the commuting and public health system by a wide range of
stakeholders. Furthermore, the model allows the dynamic simulation of potential policies over time to test their effects on an integrated set of public health outcomes.

The causal loop diagrams demonstrate that we were able to develop a consensus-based model incorporating feedback loops, which a diverse range of stakeholders was able to understand, identify with and debate. The resulting conceptual model achieved a high degree of agreement across individual and organisational stakeholders. The process of developing the qualitative model successfully incorporated knowledge about commuting and public health from stakeholders who are known to be under-represented in transport planning.

Between them, the participating stakeholders demonstrated an awareness of all the issues explored in the literature review. They were also able to demonstrate a complex understanding of the influences and wider population level impacts of current commuting patterns. This is in keeping with recent research specifically about motor-vehicle generated air pollution, which found that lay people had an understanding of air pollution risks similar to that of medical professionals (Morris & Smart, 2012).

The process of reviewing the feedback loops and identifying expected and desired trends was a kind of visioning exercise, during which participating stakeholders were able to discuss and explicitly identify desired futures. Enabling a range of stakeholders to engage in such a process is likely to lead to improved transport planning decisions for public health, as identified in the OECD sustainable transport principles (described in Section 3.1).

The cycle commuting simulation model is the first study that has enabled the integrated assessment of public health outcomes for specific active transport policies; connecting data about stated and revealed preferences in commute mode with a broad range of public health outcomes through policies to increase commuter cycling. Although policy insights from the qualitative model are valuable, the simulation model was able to test the postulated feedback loops against existing data, and identify effective policies.

The SD modelling approach deliberately “privileges the instrumental aspects of transport decisions over the emotional, symbolic and other reasons for people’s [transport choices]” (Schwanen & Lucas, 2011) (p. 11). This is consistent with the emphasis stakeholders placed on policy and infrastructure influences on commuting patterns.
Workshops have been undertaken to disseminate information about the modelling procedure and the results of the simulation model to transport planners at Auckland Transport and the NZTA. These workshops have led to peer-review of the simulation model within the transport planning discipline\textsuperscript{43} to promote its use by these agencies. Preliminary work has been undertaken to use the results of the simulation model for influencing Auckland Transport’s Sustainable Transport Plan and decision-makers have requested further scenarios to be developed. In addition, the workshop with the NZTA led to signalled changes in the Economic Evaluation Manual, the future use of the existing simulation model for the planning and justification of cycling investments, as well as interest in the SD modelling process as a group learning tool for national land transport planning.

The cycling simulation model is helpful as a tangible local example of the use of SD modelling in transport planning. The lukewarm interest and involvement of policy stakeholders in the initial process has already been strengthened by having this example demonstrating the usefulness of the methodology.

Although the group learning involved in the development of the causal loop diagrams is a crucial aspect of the modelling process and the resulting diagrams are context-specific, it is likely that the qualitative model could be used as a generalisable starting point for discussions in other cities (in New Zealand and internationally). The feedback loops identified are likely to be similar across cities, albeit with different strengths and priorities. In addition, the data sources used in this study can act as a template for the likely data needs of similar modelling efforts elsewhere.

\textbf{9.2.2. Data limitations}

The modelling highlighted limitations in the data available to develop robust simulation SD models from the causal loop diagrams. The central relationships in the model between stated preferences about different commute modes (from incomplete longitudinal survey data) and revealed preferences indicated by the census MMTW question were simplistic, although they simulated historical data reasonably well. There has been little work to link stated and revealed preferences in travel mode in New Zealand. The quality of studies assessing the effects of different kinds of cycling infrastructure on safety is generally low.

\textsuperscript{43} Undertaken by Glen Koorey, NZTA Senior Lecturer in Transport Engineering, University of Canterbury
and this detracts from the robustness of the model’s estimates. Studies assessing the effects of infrastructure on other criteria influencing cycling utility (such as whether people consider cycling more convenient) are almost non-existent. The sensitivity analysis also highlighted the need for further data about safety in numbers that is able to distinguish cause and effect through longitudinal data that accounts for the effect of infrastructure on safety and on numbers.

Data may be scarce for the simulation of many of the other causal loops identified in the qualitative modelling. For example, the relationships between dominant commuting patterns, urban design, social connection, a sense of environmental responsibility and cultural wellbeing have not been studied. Differences of spatial and temporal scale in data are also particularly problematic for modelling relationships between changes in the region’s urban landscape (e.g. through increasing density or mixed land use) and changes in the day to day sense of accessibility and time pressure that might result.

9.2.3. Critical reflections on the SD methodology and its use in this research

The experience with undertaking a participatory process to develop the qualitative model of commuting and public health led to a number of insights and reflections on participatory SD modelling and its implementation in this context. SD modelling was chosen because it seemed the methodology most likely to address the principles of decision making for urban sustainability outlined in the introduction (Section 1.2); namely transdisciplinarity, community participation, a systems perspective and the ability to incorporate aspects of equity and social justice.

As mentioned previously, the SD modelling process achieved in this study was successful in integrating transdisciplinary knowledge, particularly in the development of the causal loop diagrams, which were then incorporated into the simulation modelling. By nature, SD modelling takes a systems perspective. The study also demonstrated that SD modelling is flexible to shifts in the focus and scale of the research question. The qualitative modelling successfully incorporated and identified priorities for commuting and social justice, including enabling physical activity analyses by ethnicity. Further research, as well as improvements in data collection, would be needed to enable the stratification of further outcomes by deprivation and ethnicity.
There were a number of challenges with achieving a robust participatory SD modelling process in the context of urban New Zealand. Workshops were not well attended despite a rigorous and lengthy process of identifying appropriate stakeholders and despite evidence from a number of different sources identifying transport as a top priority for Auckland residents. This meant that many of the discussions were held with individuals outside the workshops, undermining the potential for group discussion. There are a number of possible reasons for this:

1. Participants had limited ability and willingness to engage in what was a time-consuming process. A strong tradition of participation in local government decision-making does not exist in New Zealand and there is therefore little established experience of, or commitment to, such processes.

2. The transition from the locality-based work to develop the qualitative model to the regional focus of the simulation modelling meant the process lost meaningfulness for many of the local stakeholders.

3. The representatives of local government were not high level political decision-makers and lacked adequate power to lead policy changes. Other participating stakeholders may have been aware of this and concluded that the process was not likely to lead to significant change. This issue was heightened by the governance upheaval taking place in the region.

4. The method may be less democratising than is implied in the participatory SD modelling literature. This argument is supported by Stave’s experience in urban Las Vegas (Stave, 2002, 2003), where the participants comprised a small number of technically able people in the council.

Although the cognitive maps and causal loop diagrams appeared to be well understood by participants, including engaging them in debates about the diagrams, none of the stakeholders had the necessary sense of agency to alter either the maps or the feedback loops themselves. Furthermore, only one participant felt confident explaining the causal loop diagrams to others. While a number of participants facilitated meetings to enable the presentation of the causal loop diagrams to their organisations, only one undertook the presentation of causal loop diagrams. She was a blind participant who competently presented the model to a group of disability advocates, suggesting that agency and communication of such models is possible even when circumstances may appear superficially adverse. It may be unrealistic to expect participants new to both the research
and the methods to draw maps as well as talk in an individual interview setting. Workshops are more likely to be the appropriate context for ensuring that participants are responsible for altering the maps and explaining them to each other. Exercises that improve the agency of participants in workshops should be tested in future participatory modelling studies.

These challenges with the participatory aspects of the research were compounded by two further limitations to this study. The first was its duration. The modelling steps were undertaken over four years, which is longer than many previous participatory SD modelling studies reported. This not only made it difficult for stakeholders to remain engaged, but also meant that the process was out of step with regional transport planning. Secondly, of Beall and Ford’s (2010) two options for incorporating simulation into an iterative process (Section 5.4), I chose to simulate late rather than early, as it fitted better with the transition from local to regional modelling required in this context. This choice increased the division between the qualitative and simulation sections of the process and added an extra conceptual hurdle for participants: to transition from dialogue about shared concepts of place, travel and work to dialogue about logical relationships between parameters.

In keeping with the theoretical foundations of the thesis, I entered into the research with a commitment to equity, including taking positive action to engage Māori participants, utilise a Māori model of health promotion (Te Pae Mahutonga), and test the potential for such a model for “bringing together the significant components of health promotion, as they apply to Māori health, but as they might also apply to other New Zealanders” (Durie, 1999). This was only partially and uncomfortably achieved, but engendered rich debate and initiated a related piece of research designed and undertaken by Māori for Māori.

A further limitation identified with this region-wide urban example of SD modelling is the way that aggregate regional level data assume spatial homogeneity across a city, precluding a more nuanced understanding of different spatial contexts. The positioning of SD modelling in the decision-making process is therefore important. While such modelling is likely to be helpful for high level prioritisation of funding, different approaches are needed to consider where and how to arrange infrastructure during the implementation of transport policy, accounting for spatial differences.
9.2.4. The study as action research

Consistent with the positioning of the study as action research (Section 4.5), opportunities were taken throughout the study to influence transport policy. Since policy analysts from the Auckland Regional Land Transport Strategy (ARLTS) Technical Advisory Committee were stakeholders in the study the modelling process was itself an opportunity to influence the thinking of policy makers. As a researcher I also took a number of different approaches to acting on the qualitative findings of the study. During the qualitative part of the study I took up an opportunity to provide “public health” representation on the Technical Advisory Committee responsible for the development of the 2010 ARLTS. This gave me an opportunity to share the insights from the study as it evolved, and to influence the direction of the strategy, including co-authoring the working paper on Environmental Sustainability and Public Health Policies (Kuschel & Macmillan, 2009) and having significant input into the Transport Safety working paper (Dawe, 2009). Opportunities were also taken to question the representation on both the Regional Transport Committee and the Technical Advisory Committee, particularly the lack of representation of Māori, Pacific and low income families on either committee. Members of the Maori Steering Group also took part in a Whānau Ora Health Impact Assessment, which was incorporated into the wider Health Impact Assessment of the 2010 ARLTS (Field, et al., 2009).

As the study progressed, multiple presentations were given to the changing governance of Auckland and to the region’s transport planners. In addition to direct influence on the development of policy, submissions were made to the draft RLTS and the Regional Public Transport Plan informed by the qualitative part of the study.

Further action and dissemination are planned. A report on the qualitative work aimed at the community and business stakeholders is in preparation, in addition to a report requested by the NZTA. There will also be a workshop to discuss the cycling simulation model with non-government cycling and transport advocate groups in Auckland.
9.3. Comparison with previous and coincident research

9.3.1. Studies using SD modelling to integrate transport and health

This thesis has built on previous research using SD modelling to improve democratic decision-making. In particular, this research has attempted to translate the participatory environmental modelling procedures used by van den Belt and her colleagues (2004; 2006; 1998; 2004), Antunes, Santos and Videira (2006), Videira, et al. (2005, 2009; 2004), and Beall and her colleagues (2010; 2008) into a regional urban setting.

The most similar previous research is Stave’s (2002) participatory modelling of transport policy effects on air pollution in Las Vegas. The modelling workshops reported in this study involved a small group of policy stakeholders in understanding the costs and effects of policy choices on a single public health outcome. In contrast, this research has integrated a range of public health outcomes and involved a wide group of local government, community and public health stakeholders in the development of the qualitative model.

9.3.2. Other integrated assessments of transport and health

Coincident with this research, there has been a proliferation of attempts to undertake integrated assessment for transport policy, in particular responding to an urgent need for greater understanding of the health co-benefits of mitigating transport greenhouse gas emissions. These studies have been designed to answer a range of questions and have taken different methodological approaches. The comparative risk assessment undertaken by Woodcock, et al. (2009) was the first to quantify the comparative co-benefits of transport policies to mitigate climate change, using London and Delhi as case study cities. The strengths of this assessment included the ability to use the outputs of existing transport models and convert all public health outcomes into a single measure. However, the study was separate from the policy making process; modelled only two static time points; and was not able to model the effectiveness of specific policies to increase active transport. Furthermore, the ability to incorporate business-as-usual trends was limited. Although the authors acknowledged the important role of feedback in the system they were unable to incorporate feedback into their modelling. The process limitations (the research was undertaken as a technocratic research exercise) may explain why the assessments have not yet been taken up by policy makers. The methodological limitations
mean the estimates of public health benefit may be too high and it is not clear how modelled mode shifts would be achieved. Other more recent integrated assessments (for example de Hartog, et al., 2010; Grabow, et al., 2011; Lindsay, et al., 2011) have had similar limitations.

In a different approach, Rojas-Rueda, et al. (2011) were able to use the known effects on cycling trips of a new bicycle sharing scheme in Barcelona to simulate the public health effects of a single existing intervention to increase cycling. However, they were unable to compare between policy options, or understand the dynamic effects of the existing scheme over time.

Nevertheless, these coincident studies suggest a growing and convergent area of research to influence transport policy for improved public health, equity and environmental sustainability.

9.4. Questions arising from the model and future research

The thesis represents the start of an ongoing programme of action research. Efforts to incorporate participatory SD modelling into regional and national transport planning processes are continuing. In addition, there may be opportunities to test the use of particular aspects of the modelling as part of more conventional Health Impact Assessments. For example studies could incorporate conceptual SD modelling workshops with HIA stakeholders or use simulation modelling alone to assess proposed transport policies. Such hybrid studies may bridge the considerable gap between existing HIA procedures and the approach to transport planning that would be required to fully incorporate participatory SD modelling.

The walking aspects of the causal loop diagram would be the natural next sector to incorporate into the simulation model for the Auckland region. Six of the seven remaining causal loop diagrams could also be considered for simulation (Section 6.5). The new regional governance structures are now established, opening opportunities for a more collaborative prioritisation and simulation process.

Using the basic structure of the commuter cycling simulation model to incorporate data from another high income city with more established cycling infrastructure would greatly assist with building confidence in the model’s validity. Simulating changing commuting
patterns in a city that has made a significant investment in cycling infrastructure would strengthen the robustness of assumptions. It may also be useful to incorporate aspects of the simulation model into existing European transport SD models such as ASTRA (Fiorello, Fermi, & Bielanska, 2010; Rothengatter & Schade, 2000; Schade, et al., 1999) enabling these models to integrate public health outcomes.

The systematic review of workplace travel plans and the sensitivity analysis of the simulation model have identified priorities for future epidemiological research about the effectiveness of transport interventions at changing transport mode share and improving public health. Improved research relationships between epidemiologists and local government transport planners would enhance opportunities to conduct well-designed controlled before-and-after studies of transport interventions. Community-based randomised trials would be more difficult to undertake, but the few randomised trials of workplace travel plans identified in the systematic review (in particular Mutrie, et al., 2002) suggest that they are possible.

Discussions with the authors of the coincident studies described above (Section 9.3.2) have stimulated opportunities for further research that combines different methodological approaches. For example, the visioning aspects of the qualitative SD modelling would be enhanced by incorporating visual representations of scenarios such as those under development by Visions 2030 (Tight, et al.) in the UK. Synthesising combinations of SD modelling, comparative risk assessment, agent-based modelling and spatial modelling would advance our understanding of how these approaches can contribute to transport planning that aligns sustainability, health and equity.

9.5. Conclusions

The overall objective of this research was to improve the integrated health, sustainability and equity outcomes of transport policies by testing the use of a novel modelling methodology to integrate the public health outcomes of commuting. From the literature review, policy analysis, policy case study and methodological review I made the following conclusions:

1. The links between commuting and public health form a complex system
2. Current transport planning and policies inadequately account for the full range of effects and the complexity of relationships between commuting and public health (and transport and health more generally)

3. The prevailing focus on individual behaviour change (travel demand management and workplace travel plans) to alter commuting patterns is unlikely to achieve sustainable and healthy transport goals

4. Participatory SD modelling is a promising methodology for improving the integration of public health into transport planning

After developing a participatory qualitative SD model of commuting and health and a commuter cycling simulation model to compare the integrated effects of particular policies, I draw the following conclusions about the methodology, and about policies to increase commuter cycling.

9.5.1. Participatory SD modelling for integrated assessment of transport and public health

The participatory development of the qualitative model led me to the following conclusions:

1. A modelled understanding of the commuting and public health system can be achieved, with agreement between a wide range of transdisciplinary stakeholders.

2. The collective knowledge of stakeholders accurately reflected the breadth of effects identified by the literature. However, priorities for communities differed from the emphasis placed by public health researchers. Stakeholder understandings of public health reflected an ecosystem health model.

3. In car-dominant cities, structural aspects of the transport system are likely to be more important influences on commuting behaviour than psycho-social or cultural influences.

4. Participatory SD modelling can be successfully transferred into an urban policy setting but with some pre-requisites:
   a. A stable regional governance structure;
   b. Regional level modelling needs to be accompanied by place-based narratives that allow stakeholders to identify with modelled relationships;
c. The methodology needs to be embedded into the regional planning process, be driven out of the governance organisation and include policy stakeholders with demonstrable power for change.

9.5.2. Policies to increase commuter cycling

Transitioning from qualitative causal loop diagrams to a simulation model was important for testing the presence and strength of the theoretical feedback loops, as well as for comparative testing of policy options. Simulations using the commuter cycling simulation model allowed me to draw conclusions specifically relating to policies to increase commuter cycling.

Creating safe cycling infrastructure will be crucial for increasing commuter cycling. The existing plan to develop a regional cycle network is likely to have benefits, but the possibility of it being harmful (under a worst case scenario) cannot be ruled out because it includes interventions that do not necessarily improve cycling safety, and which have only small effects on the perception of safety.

In contrast, a universal approach that progressively and proactively transforms both arterial and local roads over the next 40 years using best practice separation, intersection treatments and self explaining local roads would be needed if cycling is to assist with achieving the quantified targets in the regional transport strategy. This area-wide change would be cost effective, requiring 3% of the annual transport budget to start with, and returning approximately $20.00 in public health benefits for every dollar spent, under best estimate scenarios.

Achieving a “sweet spot” of improvements to both actual and perceived safety, and reaching the threshold for a safety in numbers effect appear necessary to achieve the increase in cycling needed to meet sustainable transport targets, while minimising the injury risk.
Appendices

A. Māori Steering Group terms of reference
B. Participant information sheets and consent forms
C. Glossary of stakeholder organisations
D. Sensitivity analysis
E. Map of the proposed Auckland Regional Cycle Network
Appendix A. Māori Steering Group terms of reference

Health Effects of Intervening in the Trip to Work
A University of Auckland Study to inform transport policy in the Auckland Region

Terms of Reference for the Maori Steering Group

Introduction
A Māori steering group for this project was suggested by Tangata Whenua of the East Tamaki area (Brownie Rauwhero and Lucy Tukua), and by te Tiriti o Waitangi Komiti of Manukau City Council, as a way of providing guidance to the project as a whole, as well as supporting the Māori members of the working/stakeholder group who would be attending the workshops.

Job description of members
Members will be representatives of regional Māori organisations, including Tangata Whenua of Greenmount East Tamaki, in positions of leadership who have the mandate to provide guidance to the project about the impacts of transport choices on whānau ora and community wellbeing. Members would need to be able to attend approximately five meetings over the course of the project.

Members

<table>
<thead>
<tr>
<th>Name</th>
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<tbody>
<tr>
<td>Rau Hoskins</td>
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<tr>
<td>Juanita de Senna</td>
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<td>Co-chair</td>
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<tr>
<td>Co-chair</td>
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<tr>
<td>Brownie Rauwhero</td>
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<tr>
<td>Julie Wade</td>
</tr>
<tr>
<td>Papaarangi Reid</td>
</tr>
<tr>
<td>Titiwhai Harawira</td>
</tr>
<tr>
<td>Edith McNeill</td>
</tr>
<tr>
<td>Tania Kingi</td>
</tr>
<tr>
<td>Megan Tunks</td>
</tr>
<tr>
<td>Tony Iwikau</td>
</tr>
<tr>
<td>Eriata Peri</td>
</tr>
<tr>
<td>Rhys Jones</td>
</tr>
<tr>
<td>Monika Ahuriri</td>
</tr>
</tbody>
</table>
Appendix A – Māori Steering Group Terms of Reference

Terms of Reference

These terms of reference are open to ongoing review and revision by the steering group.

1. The steering group will represent the views of Mana Whenua, Taura Here and urban Māori on transport choices and whānau/communtiy wellbeing
2. The steering group will meet regularly with the Māori members of the project stakeholder or working group and the Principal Investigator to inform the workshops and support these members in formulating discussion and recommendations for the workshops. This is likely to involve five meetings of approximately 1.5 hours over the course of the project (2008-2010)
3. The frequency and number of steering group meetings is flexible according to the discussion and recommendations of the steering group
4. The steering group will provide guidance to the research team about membership of the steering group, and Māori membership of the stakeholder/working group, including nominating a chair for the steering group
5. The steering group will provide guidance and input regarding matters of tikanga during the project
6. The principal investigator of the project will meet with the steering group to update the group on progress of the project, as well as provide evidence that the recommendations of the steering group have been acted upon in good faith
7. The intellectual property rights to traditional knowledge remain with the Māori participants and the steering group. There will be joint discussion between the research team, the participants and the steering group about how results are interpreted, and how the knowledge jointly generated and uncovered is used
8. If a steering group member cannot be present for a meeting, they may nominate a representative
9. Steering group members are also encouraged to attend workshops as they are able
10. The steering group will have input into how the results of the project are formulated, presented and disseminated
11. Attendance at steering group meetings will be reimbursed in vouchers at the rate of $100 per meeting
12. The costs of holding the meetings and any catering costs will be disbursed by the research team
Appendix B. Participant information sheets and consent forms

The research was originally approved by the Auckland University Human Participants Ethics Committee in 2007. When the approval was extended in 2010 changes were made to the study documents to reflect changes to the design of the study. As recommended by the ethics committee, separate study documents were developed for organisational and community stakeholders as it was not considered appropriate to provide organisational stakeholders with *koha* (token re-imbursement for participation). The statement about *koha* was therefore omitted from the organisation stakeholder information sheet. Since this was the only difference between the documents I have attached the following documents:

1. Original participant information sheet for community stakeholders
2. Original consent form for all stakeholders
3. Revised participant information sheet for community stakeholders
4. Revised consent form for all stakeholders
Appendix B – Participant information sheets and consent forms

School of Population Health

The University of Auckland
Private Bag 92019
Auckland
New Zealand.
85 Park Road, Grafton
www.health.auckland.ac.nz
Telephone: 64 9 373 7599 extn 88733
Facsimile: 64 9 373 7503
Email: a.macmillan@auckland.ac.nz

Health Effects of Intervening in the Trip to Work
A University of Auckland Study to inform transport policy in the Auckland Region

This form will be held for a period of six years

Consent Form

☒ I have read and understood the information sheet for the Health Effects of Intervening in the Trip to Work study
☒ I have had the opportunity to ask questions, and these have been answered to my satisfaction
☒ I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time. I understand I can also withdraw any information I have given up to my withdrawal, until the completion of the study.
☒ I give permission for my name to be listed as part of the stakeholder group in reports about the study:

YES / NO (please circle one)

☒ I understand that workshops will be audio taped and transcribed to help with the development of the model
☒ I have had time to consider whether to take part
☒ I know whom to contact if I have any questions about the study

I hereby consent to take part in the stakeholder group for this study

Signature ………………………………………………………….. Date DD / MM / YYYY

Full Name ………………………………………………………………….

APPROVED BY THE UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE ON 11 OCTOBER 2007 FOR 3 YEARS REFERENCE NUMBER 2007 / 310

292
Appendix B – Participant information sheets and consent forms

Community Wellbeing and the Trip to Work
A University of Auckland Study to inform transport policy in the Auckland Region

This form will be held for a period of six years

Consent Form

I have read and understood the information sheet for the Community Wellbeing and the Trip to Work project
I have had the opportunity to ask questions, and these have been answered to my satisfaction
I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time. I understand I can also withdraw any information I have given up to three months after I provided information
I give permission for my name to be listed as part of the stakeholder group in reports about the study:

YES / NO  (please circle one)

I understand that workshops may be audio taped and transcribed to help with the development of the model
I have had time to consider whether to take part
I know whom to contact if I have any questions about the study

I hereby consent to take part in the stakeholder group for this study

Signature  …………………………………………………… Date     DD  / MM /  YYYY
Full Name ……………………………………………………………

APPROVED BY THE UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE ON 11 OCTOBER 2007 FOR 3 YEARS REFERENCE NUMBER 2007/310
Appendix C. Glossary of participating organisations

**Accident Compensation Corporation** the Crown organisation providing personal injury cover to New Zealand residents and visitors, who also have a role in injury prevention (including research) and rehabilitation

**Auckland District Māori Council** a pan-tribal organisation to address urban Māori issues via relationships with the Auckland District Council

**Auckland Disability Law Service** a free community law service providing access to legal services for disabled people, as well as advocating for awareness around disability rights and legislation, and assistance with law reform

**Auckland Regional Council** (ARC) the regional council responsible for environmental protection and region-wide transport planning, superseded by Auckland Council in late 2010

**Auckland Regional Public Health Service** Auckland’s regional public health agency, working across the three District Health Boards, and fulfilling the statutory public health roles in local government (including public health representation on the Regional Transport Committee)

**Auckland Regional Transport Authority** (ARTA) a subsidiary authority of the Auckland Regional Council, responsible for the implementation of the Auckland Regional Land Transport Strategy, disestablished in 2010 and later replaced by a Community-Controlled Organisation, Auckland Transport

**DesignTRIBE Architects** specialise in the design of kaupapa Māori buildings and communities, including both architecture and urban design

**Greenmount East Tamaki Business Association** the local business association in the qualitative study area

**Hapai te Hauora Tapui** Auckland Region’s Māori public health provider who coordinates a range of Māori public health services in the region via a tripartite agreement between three major iwi trusts: Te Runanga o Ngati Whatua, Te Whanau o Waipareia Trust and Raukura Hauora o Tainui

**Manukau City Council** the City Council responsible for land use and some transport planning in the qualitative study area

**Manukau City Council Disability Steering Group** A group of representatives of people with disabilities involved in policy development and advocacy in the qualitative study area

**Manukau City Council Treaty of Waitangi Unit** the group within Council responsible for relationships with *tangata whenua* (superseded in late 2010 by the Māori Strategy and Relations department within Auckland Council)
Appendix C – Glossary of participating organisation

**Manukau City Council Treaty of Waitangi Committee** the group providing representation of *tangata whenua* (groups exerting ancestral rights) over the Manukau City Council jurisdiction, to provide strategic advice, recommendations and submissions to the Council (superseded in late 2010 by the regional Māori Statutory Board)

**Manukau Institute of Technology** (MIT) a large tertiary institute in the qualitative study area

**Manukau Urban Māori Authority** An urban Māori social services provider in South Auckland, delivering programmes that support young Māori to stay in school or gain employment, provide budgeting and restorative justice services and improve the cultural and language knowledge of Māori offenders

**Māori Injury Prevention Group** an informal national network of Māori injury prevention professionals

**Otara Community Board** one of the local community boards (mixture of local elected and appointed members) in the qualitative study area, representing a suburb with high deprivation

**Regional Travel Demand Management Group** representatives across all councils and ARTA to discuss and be a community of practice about activities related to travel demand management, including school and workplace travel plans

**Tainui Iwi** one of the iwi exerting *mana whenua* (ancestral rights) over the qualitative study area

**Te Kupenga Hauora Māori** the Māori Health Research Centre within the Faculty of Medical and Health Sciences, The University of Auckland

**Te Ora o Manukau/Manukau the Healthy City** the WHO Healthy Cities programme in the qualitative study area
Appendix D. Sensitivity Analysis

This section prioritises the most uncertain parameters and discusses the sensitivity of the model their variation. I have tested the sensitivity of the model to the most uncertain parameters individually to assess their effect on model behaviour and the comparative magnitude of outcomes.

The mode utility equation is relates survey data with mode share in a simple product equation without weighting of criteria. The relationship between the survey and mode share has not been previously tested in Auckland. Although other studies have used a logit approach with different weightings applied to each criterion, the simple product model fits historical data reasonably well. Future testing of the model should test different approaches to this equation.

The data sources for all parameters have been described in detail in Chapters 7 and 8, including sources of uncertainty and aspects of quality. I have used these descriptions to identify the most uncertain parameters for sensitivity testing. Decisions to include variables in the sensitivity analysis were made on the basis of multi-dimensional considerations, including aspects of study design, data completeness, applicability to the Auckland context and how well the data fit the model purpose.

Those variables tested in the sensitivity analysis are described in Table D-1 along with the approach taken to the sensitivity analysis. Judgement about multi-dimensional aspects of data quality was used to identify the most uncertain data sources that are also most likely to affect the model behaviourally. For data from cohort studies, modelled forecasts using sampled measurements and controlled before-and-after studies I have used reported confidence intervals as the range for sensitivity testing and a normal distribution for Monte Carlo simulation. For survey data I have used judgement to identify a range and a normal distribution for the Monte Carlo simulation. For variables based on expert opinion I have used judgement to identify a wider range and a uniform distribution for the Monte Carlo simulation. For parameters with a normal distribution, standard deviations were calculated such that 3 standard deviations included upper and lower bounds.
## Appendix D – Sensitivity Analysis

<table>
<thead>
<tr>
<th><strong>Parameter</strong></th>
<th><strong>Comments on data</strong></th>
<th><strong>Approach to sensitivity analysis</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mode share and population</strong></td>
<td>Change in commuting population: Census data trends used in forecast modelling</td>
<td>Normal distribution, upper and lower bounds for population growth (1 and 1.8%)</td>
</tr>
<tr>
<td></td>
<td>Mode normal: No data available – stakeholder opinion</td>
<td>Uniform distribution 0.5-1.0</td>
</tr>
<tr>
<td></td>
<td>Time to change behaviour: Judgement</td>
<td>Random distribution 2 months-3 years</td>
</tr>
<tr>
<td><strong>Outcomes</strong></td>
<td></td>
<td></td>
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<tr>
<td><strong>Air pollution</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM$_{10}$ per km effects</td>
<td>Results of observational studies combined with geographical modelling of vehicle pollution used to develop per km travelled effects specific to Auckland (HAPINZ 2010)</td>
<td>Considered underestimate, per km effects doubled, normal distribution with mean 1.5 times best estimate and standard deviation best estimate/6</td>
</tr>
<tr>
<td>Light vehicle PM$_{10}$ emission improvements</td>
<td>Fleet measurements</td>
<td>Level of uncertainty not known – no further improvement and double improvement tested</td>
</tr>
<tr>
<td><strong>Injury</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ratio of commuting light vehicles to other light vehicles at peak time</td>
<td>No data available – stakeholder opinion</td>
<td>Uniform distribution 0.4-0.8</td>
</tr>
<tr>
<td>Ratio of light vehicles arterial:local roads at peak times</td>
<td>No data available – stakeholder opinion</td>
<td>Uniform distribution 0.7-0.9</td>
</tr>
<tr>
<td>Ratio of cyclists arterial:local roads at peak time</td>
<td>No data available – stakeholder opinion</td>
<td>Uniform distribution 0.3-0.7</td>
</tr>
<tr>
<td>Safety in numbers</td>
<td>Ecological studies, administrative injury and census data, stakeholder opinion</td>
<td>Sensitivity to Jacobsen’s assumption and a lower threshold (5% suggested by Turner)</td>
</tr>
<tr>
<td>Effect of vehicle numbers on collisions</td>
<td>Crash prediction modelling based on crash, cycle count and motor vehicle count data for New Zealand cities</td>
<td>Know there is a 0,0 point and current motor vehicle and crash counts, but sensitivity tested to altering the shape of the graphical function</td>
</tr>
</tbody>
</table>
### Appendix D – Sensitivity Analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments on data</th>
<th>Approach to sensitivity analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect of LV speed on crash fatality ratio</td>
<td>Accident reconstruction, mathematical modelling,</td>
<td>Difficult to do – from injury data and speed data we can work out where we are on the graph, and the relationship between speed and CFR is reasonably well accepted – not tested</td>
</tr>
<tr>
<td><strong>Physical activity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effect of cycling on all-cause mortality</td>
<td>Cohort studies of commuter cycling – assume a linear dose response, and that “average” commuter cycling can be representative</td>
<td>Normal distribution using SDs from cohort studies (RR 0.57-1.01): mean 0.79, standard deviation 0.07</td>
</tr>
<tr>
<td>Lead-in/lead-out times for effect of physical activity on all-cause mortality</td>
<td>Implicit in cohort studies, interpreted by the candidate</td>
<td>Uniform distribution between 1 and 5 years</td>
</tr>
<tr>
<td><strong>Greenhouse gas emissions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LV fleet CO₂ emissions</td>
<td>VEPM model</td>
<td>Uncertainty not known, but likely to grow with time - no further improvement in LV CO₂ emissions and double the improvement projected by VEPM tested</td>
</tr>
<tr>
<td><strong>Fuel cost savings</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>VEPM model</td>
<td>Uncertainty not known, but likely to grow with time - no further improvement in LV fuel consumption and double the improvement projected by VEPM tested</td>
</tr>
<tr>
<td>Diesel and petrol costs</td>
<td>Forecast modelling combining expectations of extraction and refining on the supply side, with growing market demand</td>
<td>Normal distribution, using upper and lower bounds from Donovan, et al.</td>
</tr>
<tr>
<td><strong>Policies</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infrastructure costs</td>
<td>Auckland Transport estimates</td>
<td>Normal distribution: means midpoint of range provided, standard deviations calculated as the range/6</td>
</tr>
<tr>
<td><strong>Regional cycle network</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Appendix D – Sensitivity Analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments on data</th>
<th>Approach to sensitivity analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect of on-road lanes on collisions</td>
<td>Poorly controlled before-after studies</td>
<td>Wide confidence intervals in studies tested using normal distribution of relative risk (0.83-1.5)</td>
</tr>
<tr>
<td>Effect of on-road lanes on sense of safety</td>
<td>Stated preference survey of cyclists in Copenhagen, No confidence intervals reported but comparative differences supported by other studies</td>
<td>Normal distribution, mean 0.58, standard deviation 0.06</td>
</tr>
<tr>
<td>Effect of on-road lanes on cycling good for work</td>
<td>No data available, candidate judgement supported by stakeholder opinion</td>
<td>Uniform distribution between 0 and 0.5</td>
</tr>
<tr>
<td>Effect of off-road tracks on collisions</td>
<td>Poorly controlled before-after studies</td>
<td>Wide confidence intervals in studies tested using normal distribution (0.9-3.5)</td>
</tr>
<tr>
<td>Effect of off-road tracks on sense of safety</td>
<td>Ecological study with dose-response combined with judgement</td>
<td>Normal distribution mean 0.4, standard deviation 0.06</td>
</tr>
<tr>
<td>Effect of off-road tracks on cycling good for work</td>
<td></td>
<td>Uniform distribution 0 to 0.3</td>
</tr>
<tr>
<td>Effect of bus-bike lanes on collisions</td>
<td>Poorly controlled before-after study</td>
<td>Confidence intervals not supplied. Range of point estimates in study used</td>
</tr>
<tr>
<td>Effect of bus-bike lanes on sense of safety</td>
<td>Judgement supported by stakeholder opinion</td>
<td>Uniform distribution 0 to 0.3</td>
</tr>
<tr>
<td>Effect of bus-bike lanes on cycling good for work</td>
<td>Judgement supported by stakeholder opinion</td>
<td>Uniform distribution 0 to 0.4</td>
</tr>
<tr>
<td><strong>Arterial separated bike lanes (ASBL) and best practice intersections (BPI)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effect of ASBL on collisions</td>
<td>Controlled before-after studies</td>
<td>Normal distribution of relative risk using upper and lower bounds from all studies (0.6-1.1)</td>
</tr>
<tr>
<td>Effect of ASBL on sense of safety</td>
<td>Stated preference survey of cyclists in Copenhagen, No confidence intervals reported but comparative differences supported by other studies</td>
<td>Normal distribution of effect with mean 0.6 and standard deviation 0.06</td>
</tr>
</tbody>
</table>
### Appendix D – Sensitivity Analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments on data</th>
<th>Approach to sensitivity analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect of ASBL on good for work</td>
<td>Judgment supported stakeholder opinion</td>
<td>Uniform distribution of effect 0.2-0.6</td>
</tr>
<tr>
<td>Effect of BPI on collisions</td>
<td>Poorly controlled before-after studies</td>
<td>Normal distribution of relative risk using upper and lower bounds from studies of advanced stop lines (0.61-1.16)</td>
</tr>
<tr>
<td>Effect of BPI on sense of safety</td>
<td>Judgement supported by stated preference survey in Copenhagen</td>
<td>Uniform distribution of effect between 0 and 0.2</td>
</tr>
<tr>
<td><strong>Self explaining roads (SER)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effect of SER on collisions</td>
<td>OECD speed management report – source data not known</td>
<td>Uniform distribution of relative risk between 0.4 and 0.8</td>
</tr>
<tr>
<td>Effect of SER on cyc good for work</td>
<td>Judgement supported by stakeholder opinion</td>
<td>Uniform distribution between 0 and 0.3</td>
</tr>
<tr>
<td>SER on cycling sense of safety</td>
<td>Judgement supported by stakeholder opinion</td>
<td>Uniform distribution between 0 and 0.4</td>
</tr>
<tr>
<td>SER on light vehicles hassle free</td>
<td>Combined reduction and diversion of traffic supported</td>
<td>Normal distribution, mean -0.3, standard deviation 0.06</td>
</tr>
<tr>
<td>SER on LV arterial</td>
<td>by local and international before-after studies</td>
<td>Normal distribution between 0.55 and 0.95</td>
</tr>
<tr>
<td>SER on proportion cycling arterial</td>
<td>Judgement supported by stakeholder opinion</td>
<td>Uniform distribution between 0.3 and 0.9</td>
</tr>
<tr>
<td>SER local speed</td>
<td>Local controlled before-after study supported by international studies</td>
<td>Normal distribution 20-40kph</td>
</tr>
</tbody>
</table>

Table D-1 Parameters tested in the individual sensitivity analysis

### D.1. Population and mode share parameter testing

**Population and mode share**

Statistics New Zealand provides low, medium and high population projections for Auckland between 2006 and 2031, with average annual percent increases of 1.0, 1.4 and 1.8% respectively. In the business-as-usual scenario, the model is behaviourally stable to this range of population growth, and the order of magnitude of outcomes does not change.
Appendix D – Sensitivity Analysis

However, the high population projection results in a later peak in total CO$_2$ emissions as can be seen in Figure D-1. Simulating the range of projections under scenario 5 changes neither the shape nor the order of magnitude of outcomes.

![Figure D-1](image)

Figure D-1 Total annual CO$_{2eq}$ emissions from commuting light vehicles under the range of population assumptions: 1 low (1.0%), 2 medium (1.4%) and high (1.8%)

The model is behaviourally stable to all mode utility criteria. Sensitivity testing of all criteria over the distributions specified in Table D-1 (and 30 runs for each analysis) results in losing the ability to distinguish between the RCN and SER policies for cycle mode share outcomes. The most uncertain parameter determining mode share is the “normality” criterion. This creates the widest variation in mode share and public health outcomes over time, but the ability to distinguish comparative order of magnitude between policies is retained, except between the RCN and SER policies. The range of mode share outcomes from varying the initial value for the proportion of people thinking cycling is normal are shown in Figure D-2.
This variation in mode share has a range of effects on outcomes of interest. Indicative examples are provided below in Figure D-3. As can be seen from these examples, outcomes are behaviourally and order-of-magnitude stable to varying the assumptions about this criterion.
Appendix D – Sensitivity Analysis

The model was much less sensitive to random testing across a uniform distribution for the normality criteria for all other modes.
The model was insensitive to changes in the “time to change behaviour” variable between 2 months and 3 years. Below 2 months the model begins to become unstable at low levels of cycling because of rapid fluctuations.

D.2. Outcomes parameter testing

Air pollution outcomes

Doubling the per km estimates for all air pollution outcomes has the effect demonstrated in the output below (Figure D-4), where the lower curves represent best estimate and the upper curves are sensitivity analyses under all scenarios. All outcomes demonstrated similar behavioural and order-of-magnitude stability.

The graphical function for light vehicle PM$_{10}$ emissions trends was varied to represent an upper bound of no further improvement after 2012, and a lower bound of double the improvement estimated by the VEPM model from 2012 (Figure D-5). Resulting air pollution outcomes are shown below for all scenarios. These vary both behaviourally and in the order of magnitude of outcomes.
Appendix D – Sensitivity Analysis

All air pollution mortality outcomes show similar behavioural stability and order-of-magnitude variation in response to testing under all policy scenarios. The air pollution mortality outcomes are shown below (Figure D-6).

Figure D-5 Graphical functions for high, best and low light vehicle PM$_{10}$ emissions improvement (upper bound is double the level predicted by VEPM, lower bound is no further improvement after 2012)

Figure D-6 Air pollution mortality under strongest (top) and weakest (bottom) light vehicle PM$_{10}$ emission improvement assumptions under all policy scenarios
Cumulative outcomes for all scenarios are summarised in Table D-2.

<table>
<thead>
<tr>
<th></th>
<th>PM$_{10}$ mortality</th>
<th>Hospitalisations</th>
<th>COPD incidence</th>
<th>Cancer incidence</th>
<th>Restricted activity days</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 (RCN)</td>
<td>3-20</td>
<td>1-11</td>
<td>3-24</td>
<td>0-0.02</td>
<td>4550-30,000</td>
</tr>
<tr>
<td>3 (ASBL)</td>
<td>9-64</td>
<td>5-34</td>
<td>10-76</td>
<td>0.01-0.06</td>
<td>13,554-95,000</td>
</tr>
<tr>
<td>4 (SER)</td>
<td>13-89</td>
<td>7-48</td>
<td>15-106</td>
<td>0.01-0.08</td>
<td>18,569-131,000</td>
</tr>
<tr>
<td>4 (ASBL + SER)</td>
<td>27-188</td>
<td>14-102</td>
<td>33-224</td>
<td>0.02-0.2</td>
<td>39,368-278,000</td>
</tr>
</tbody>
</table>

Table D-2: Cumulative Air pollution mortality and morbidity savings to 2051 tested against a range of emission improvement scenarios

**Cyclist injury**

The proportion of light vehicles that are commuting vehicles determines the total number of light vehicles at peak travel times. Varying the proportion of light vehicles that are commuting across a uniform distribution causes increasing variation in injury outcomes as the commuter cycling mode share increases (Figure D-7 and Figure D-8). Injury outcomes are behaviour and order-of-magnitude stable.

![Figure D-7 Sensitivity testing of cyclist injuries against variation in assumptions about the light vehicle volumes at peak travel times for all policy scenarios](image-url)
Appendix D – Sensitivity Analysis

Injury rates are somewhat more sensitive to varying this parameter, with some loss of the ability to distinguish between scenarios, particularly between business-as-usual and the regional cycle network.

Varying the proportion of light vehicles on arterial and local roads has a similar but weaker effect on injury outcomes.

The following outputs demonstrate the sensitivity of fatal and serious injuries to the adapted safety in numbers threshold (Figure D-9). Runs 1 and 2 in the graphs assume a 10% commuter cycling mode share threshold before safety in numbers begins to have an effect, and runs 3 and 4 use a 5% threshold. Runs 1 and 3 are simulating scenario 3 (ASBL) and runs 2 and 4 are for scenario 5 (ASBL + SER).
This assumption does not change the shape or order of magnitude over time, but for scenario 5 a lower threshold represents a saving of approximately 60 serious and fatal injuries per year by 2051.

On the other hand, using Jacobsen’s assumptions, a very different pattern emerges. The following outputs (Figure D-10) are for all five scenarios under Jacobsen’s assumption, demonstrating that the model is behaviourally sensitive to the assumption of a threshold and the order of magnitude of the safety in numbers effect.
The best estimate for the effect of vehicle numbers on collisions on local roads is that a doubling of vehicles leads to a doubling of collisions. To test sensitivity to this assumption I used a lower bound of a 30% effect of doubling vehicles, and an upper bound of 70%. The graphical functions used are therefore shown in Figure D-11.

Figure D-11 Graphical functions for low, best estimate and high effects of light vehicle numbers on cyclist-vehicle collisions
Injury outcomes are behaviour and order-of-magnitude stable, and are relatively insensitive to these assumptions.

**Physical activity**

The relative risk of for all-cause mortality of commuter cycling was varied over the confidence interval range from the two cohort studies previously described (0.57-1.01) using a normal distribution. The model was not behaviourally sensitive, but the all-cause mortality savings varied in order of magnitude for all scenarios as shown in Table D-3. There was also overlap in outcomes between scenarios, even between scenarios 2 and 5.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>All-cause mortality savings (number of lives)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 (RCN)</td>
<td>7-780</td>
</tr>
<tr>
<td>3 (ASBL)</td>
<td>263-2394</td>
</tr>
<tr>
<td>4 (SER)</td>
<td>13-808</td>
</tr>
<tr>
<td>5 (ASBL + SER)</td>
<td>730-5154</td>
</tr>
</tbody>
</table>

Table D-3 Range of all-cause mortality savings in response to variation in relative risk of all-cause mortality due to commuter cycling

The lead in/lead out time for the effect of commuter cycling on all-cause mortality was tested by randomly sampling from a uniform distribution between 1 and 5 years in multiple simulations. Table D-4 shows the range of all-cause mortality savings under scenarios 2 to 5. Differences in order of magnitude are seen, but the model is behaviourally stable. Although there is again some overlap between scenarios, the model retains its ability to distinguish between scenarios 2 and 5.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>All-cause mortality savings (number of lives)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 (RCN)</td>
<td>178-2739</td>
</tr>
<tr>
<td>3 (ASBL)</td>
<td>1400-3773</td>
</tr>
<tr>
<td>4 (SER)</td>
<td>298-2758</td>
</tr>
<tr>
<td>5 (ASBL + SER)</td>
<td>3547-5527</td>
</tr>
</tbody>
</table>

Table D-4 Range of all-cause mortality savings in response to Uniform variation in the lead in lead out time
Appendix D – Sensitivity Analysis

**Greenhouse gas emissions**

The graphical function of projected improvements in greenhouse gas emissions from the light vehicle fleet was varied to represent an upper bound of no further improvement from 2012, and a lower bound of double the improvement projected by the VEPM model (Figure D-12).

![Figure D-12 Graphical functions for high, best estimate and low improvements in light vehicles CO₂ emissions](image)

The graph below (Figure D-13) demonstrates total CO₂eq emissions from the commuting fleet for the upper and lower bounds, under all scenarios. Curves 1 to 5 use the upper bound, and curves 6 to 10 the lower bound. Per capita emissions demonstrate very similar behavioural and order-of-magnitude sensitivity.

![Figure D-13 Upper and lower bounds for total CO₂ emissions (megatons) from the commuting fleet under all policy scenarios](image)
Table D-5 summarises the range of cumulative greenhouse gas emissions savings for all scenarios from the sensitivity analysis to 2051.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total commuting CO₂eq emissions (Mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 (RCN)</td>
<td>1-5</td>
</tr>
<tr>
<td>3 (ASBL)</td>
<td>5-15</td>
</tr>
<tr>
<td>4 (SER)</td>
<td>7-21</td>
</tr>
<tr>
<td>5 (ASBL + SER)</td>
<td>15-44</td>
</tr>
</tbody>
</table>

Table D-5 Total cumulative greenhouse gas emissions savings from commuting to 2051 under all scenarios

Under the upper bound emission trends no scenario would meet a source specific council target to halve commuting per capita greenhouse gas emissions by 2040 compared with 2006 levels. In contrast, using lower bound assumptions all scenarios, including business-as-usual would meet the target for commuting (Figure D-14).

Fuel cost savings

The two most uncertain parameters in this sector are graphical functions for projected fuel consumption improvements and projected petrol and diesel prices.
Appendix D – Sensitivity Analysis

Fuel consumption assumptions have been tested using an upper bound of no further improvement and a lower bound of double the improvement projected by the VEPM model (Figure D-15).

![Figure D-15 Graphical functions for high, best estimate and low improvements in light vehicle fuel consumption](image)

Outcomes are behaviourally stable but order-of-magnitude sensitive to these assumptions, as seen in the curves below for total fuel cost savings under all policy scenarios (Figure D-16). Table D-6 shows the range of cumulative total fuel cost savings for all scenarios to 2051:
Appendix D – Sensitivity Analysis

Figure D-16 Total fuel cost savings for all policy scenarios under upper (top) and lower (bottom) bounds for improvements in light vehicle fuel consumption

Table D-6 Sensitivity range of cumulative total fuel cost savings for all scenarios to 2051

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total fuel cost savings (million NZD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (BAU)</td>
<td>146-262</td>
</tr>
<tr>
<td>2 (RCN)</td>
<td>497-1095</td>
</tr>
<tr>
<td>3 (ASBL)</td>
<td>1257-2947</td>
</tr>
<tr>
<td>4 (SER)</td>
<td>510-1142</td>
</tr>
<tr>
<td>5 (ASBL + SER)</td>
<td>2552-6137</td>
</tr>
</tbody>
</table>

From the graphs and table above, it can be seen that the model is behaviourally stable to changes in assumptions about fuel consumption improvements over time. Scenarios 2 and 4 are order-of-magnitude sensitive, ranging from the hundreds to the thousands of
millions of dollars saved. Savings per person also demonstrate order-of-magnitude variation depending on assumptions about fuel efficiency over time, from $420 to $1240 per year.

The model was tested for sensitivity to price trends for diesel and petrol using the lowest and highest estimates from Donovan’s Price Forecasts report (Figure D-17).

The range of cumulative fuel cost savings to 2051 under all scenarios is summarised in Table D-7 below and the shape of total fuel cost savings over time under all scenarios is demonstrated in Figure D-18.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total fuel cost savings (million NZ dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (BAU)</td>
<td>117-315</td>
</tr>
<tr>
<td>2 (RCN)</td>
<td>372-1273</td>
</tr>
<tr>
<td>3 (ASBL)</td>
<td>924-3386</td>
</tr>
<tr>
<td>4 (SER)</td>
<td>381-1322</td>
</tr>
<tr>
<td>5 (ASBL + SER)</td>
<td>1867-7018</td>
</tr>
</tbody>
</table>

Table D-7 Sensitivity range of cumulative fuel cost savings (million NZ dollars) to 2051 using upper and lower bounds for diesel and petrol price projections for all scenarios
Results exhibit some behavioural as well as order-of-magnitude differences between the lower and upper estimates, although all behaviours are plausible. Under low fuel cost estimates total savings flatten off over time as growth in cycling mode share tails off. But under high estimates growth in fuel prices continues to drive a growth in fuel cost savings over time. Even under this extreme analysis the model is able to distinguish all scenarios from business-as-usual, with overlapping ranges for scenarios 2, 3 and 4, but a clear distinction between scenario 5 and all other scenarios.
D.3 Policy parameter testing

Infrastructure costs

The sensitivity of total and annual policy costs was tested to the range of infrastructure costs provided by Auckland transport (summarised in Table D-8). The best estimate cost for the SER pilot study was used as an upper bound (range $100,000-300,000). A range of $100,000-300,000 was also used for the ASBL policy.

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Cost per km range</th>
<th>Cost per km modelled</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-road marked cycle lane (2 sides)</td>
<td>$5-40,000 ($15,000)</td>
<td>$15,000</td>
</tr>
<tr>
<td>Shared bus-bike lane (2 sides)</td>
<td>$50-200,000 ($100,000)</td>
<td>$100,000</td>
</tr>
<tr>
<td>Off-road shared path</td>
<td>$75-400,000 ($150,000)</td>
<td>$150,000</td>
</tr>
<tr>
<td>On-road separated lane + intersection treatment</td>
<td>None supplied</td>
<td>$200,000</td>
</tr>
<tr>
<td>Self explaining local road</td>
<td>$300,000</td>
<td>$300,000</td>
</tr>
</tbody>
</table>

Table D-8 Estimated costs per km of policy interventions

The ranges for total and annual average costs to 2051 under all policy scenarios are shown in Table D-9.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total cost to 2051 (million NZ dollars)</th>
<th>Average annual cost (million NZ dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 (RCN)</td>
<td>128-715</td>
<td>4.4-24.7</td>
</tr>
<tr>
<td>3 (ASBL)</td>
<td>754-2262</td>
<td>19.3-58</td>
</tr>
<tr>
<td>4 (SER)</td>
<td>759-2278</td>
<td>19.5-58</td>
</tr>
<tr>
<td>5 (ASBL + SER)</td>
<td>1513-4540</td>
<td>39-116</td>
</tr>
</tbody>
</table>

Table D-9 Sensitivity ranges for total and average annual costs of intervention policies (million NZ dollars)

The model is order-of-magnitude sensitive to these assumptions for scenarios 2 and 5.
Regional cycle network (RCN)

A best and worst case scenario for each uncertain parameter was undertaken. For the effect on collision, differences in mode share, perception of safety and injury outcomes are described. For other variables only the varying effect on cycle mode share is reported.

Worst and best case scenarios were simulated using the range of reported confidence intervals for component relative risks of cycle crashes in the literature. A best case scenario for the effects on the RCN on cyclist-vehicle collisions sees the RCN result in a cycling commute mode share of nearly 6% by 2051, with 40% people considering cycling always/mostly safe. By 2051 there would be 310 fatal and serious injuries/year, and a serious injury rate of 6/1000 cyclists per year and gradually rising because of growing vehicle numbers. In a worst case scenario, the same mode share is achieved, with a similar perception of safety, but 500 fatal and serious cyclist injuries and a large increase in the rate of serious injury to 10/1000 cyclists per year. The behavioural stability of injury outcomes under these upper and lower bounds is demonstrated in Figure D-19.

Running 30 simulations that randomly sampled from normal distributions for the component relative risks across the confidence intervals indicated by the literature gives a narrower and more conservative range for the injury outcomes: 200-335 serious and fatal injuries per year by 2051 with an injury rate of between 6.3 and 8.9/100,000 cyclists per year.

Random simulation from normal and uniform distributions for the effects of aspects of the RCN on sense of safety results in a range of cycling commute mode shares under the RCN of 4 to 7%. Random simulation across a uniform distribution for the effects of RCN components on cycling as a good mode for work results in a range of effects on cycling commute mode share between 2 and 8% by 2051.
Arterial segregated cycle lanes (ASBL)

Using upper and lower bounds from confidence intervals reported in the literature, a best case scenario for the combined effect of ASBL with best practice intersections on cyclist-vehicle collisions sees a cycling commute mode share of 18% by 2051 with 70% people considering cycling always/mostly safe. Five hundred fatal/serious injuries per year result by 2050 (similar to the worst case scenario for the RCN) but with a serious injury rate of 3.3/1000 cyclists per year. The worst case scenario has a similar effect on mode share and perception of safety but with 960 fatal/serious cyclist injuries per year and an injury rate of 6.4/1000 cyclists per year, slightly increasing over time. The behaviours of cycling injury outcomes over time for the best and worst cases are shown in Figure D-20.
Analysing across 30 simulations using a normal distribution for these two relative risks again provides a narrower range of 233-563 serious and fatal injuries/year by 2051 and a serious injury rate of 3.57-5.75/1000 cyclists/year.

Random simulation across appropriate normal and uniform distributions for effects of the ASBL policy on cycling sense of safety and cycling good for work results in cycling mode shares between 10 and 24% by 2051.

**Self explaining local roads (SER)**

Worst and best case scenarios for the effect of SER on vehicle-cyclist collisions have similar effects on mode share. In a best case scenario this policy results in 158
serious/fatal cyclist injuries per year by 2051, and an injury rate of 2.9/1000 cyclists/year. At its worst the SER policy has similar effects, resulting in 182 serious/fatal injuries per year and an injury rate of 3.4/1000 cyclists per year by 2051.

Other effects of SER policy also have an impact on cycling injury outcomes. Best and worst case estimates for the effect of SER on the average speed of local roads result in a narrow range of annual serious/fatal cyclist injuries between 145-180 and a range of injury rates between 2.6 and 3.3/1000 cyclists per year. Testing the effect of SER on the proportion of peak time light vehicles on arterial and local roads using a range of reductions between 5 and 45% makes no difference to injury outcomes. Injury outcomes for this policy are most sensitive to assumptions about the effect of SER on the proportion of peak time cycling spent on arterial roads (baseline is 50%). A range of effects between a reduction to 45% and a reduction to 15% results in a range of serious/fatal injuries of 111-212/year and a range of injury rates between 1.8 and 4/1000 cyclists by 2051.

Random simulation across normal and uniform distributions for the effect of the SER policy on cycling perception of safety, cycling good for work and light vehicles hassle free results in the wide ranges for mode shares seen in Table D-10.

<table>
<thead>
<tr>
<th>Mode share</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycling</td>
<td>0.02-0.16</td>
</tr>
<tr>
<td>Light vehicle</td>
<td>0.4-0.7</td>
</tr>
<tr>
<td>Public transport</td>
<td>0.16-0.37</td>
</tr>
<tr>
<td>Walking</td>
<td>0.08-0.18</td>
</tr>
</tbody>
</table>

Table D-10 Sensitivity ranges for all mode shares under the self explaining roads policy

**Mixed universal policy (ASBL + SER)**

Best and worst case scenarios were tested using the range of collision rates for the components of policies tested earlier, as well as the range for the SER proportion of cyclists on arterial roads. These two simulations result in a range of serious and fatal injuries between 223 and 1177/year by 2051 and injury rates between 0.7 and 3.6/1000 cyclists per year (Figure D-21).
Simulating this policy over a range of effects using normal distributions for the relative risk estimates results in a narrower range of cyclist serious fatal injuries (201-755 per year by 2051) and injury rates (1.1 to 2.7/1000 cyclists per year by 2051), as shown in Figure D-22.

Multiple simulations combining the normal and uniform distributions for the effects of all the components of this scenario on the determinants of mode share result in a behaviour and order-of-magnitude stable range of cycling mode share between 20 and 52% by 2051(Figure D-23).
Appendix D – Sensitivity Analysis

Figure D-22 Range of injury outcomes for ASBL + SER policy seen under random simulation across normal distributions for the effect of components on collisions and the proportion of cyclists travelling on arterial roads.

Figure D-23 Mode share outcomes for ASBL + SER policy simulated using random sampling from normal and uniform distributions of component criteria.
Appendix E. Auckland’s planned Regional Cycle Network

The Regional Cycle Network was developed by Auckland Transport and local councils. Each council is working on their Local Plan transport strategy. As a result, the Regional Cycle Network by 2021. The overall goal is to double the number of cycle trips around the region.

As well as showing the routes that make up this first half of the network, the map also illustrates routes that will provide better connectivity when the entire network is completed, but are not currently planned to be implemented before 2019.

The Regional Cycle Network as shown here covers more than 800 kilometres, of which more than 180 kilometres already exist. Potential links that could connect key destinations to the network would close many more kilometres of gap.
Chapter 10. References


References


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