

A Novel Approach for the Development of Policies for Socio-Technical Systems



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*A thesis submitted for the degree of
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Dedication

To my amazing parents, Neda and Ali.

You raised me in the aftermath of a revolution, during the longest war in the twentieth century, under sanctions and while facing many other hurdles; all this time, you made many sacrifices for me and gave me unconditional love and support. You taught me to be positive, to love and see the beauties of this world, and instilled in me the ethic to work hard and to fight for my dreams. No matter what I do, I will never be able to thank you enough. I am grateful to you and love you with all my heart.

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Abstract

The growth in the interdependence and complexity of socio-technical systems requires the development of tools and techniques to aid in the formulation of better policies. The efforts of this research focus towards developing methodologies and support tools for better policy design and formulation. In this thesis, a new framework and a systematic approach for the formulation of policies are proposed. Focus has been directed to the interactions between policy measures, inspired by concepts in process design and network analysis. Furthermore, we have developed an agent-based approach to create a virtual environment for the exploration and analysis of different configurations of policy measures in order to build policy packages and test the effects of changes and uncertainties while formulating policies. By developing systematic approaches for the formulation and analysis of policies it is possible to analyse different configuration alternatives in greater depth, examine more alternatives and decrease the time required for the overall analysis. Moreover, it is possible to provide real-time assessment and feedback to the domain experts on the effect of changes in the configurations. These efforts ultimately help in forming more effective policies with synergistic and reinforcing attributes while avoiding internal contradictions. This research constitutes the first step towards the development of a general family of computer-based systems that support the design of policies. The results from this research also demonstrate the usefulness of computational approaches in addressing the complexity inherent in the formulation of policies. As a proof of concept, the proposed framework and methodologies have been applied to the formulation of policies that deal with transportation issues and emission reduction, but can be extended to other domains.

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First and foremost, I would like to thank my DPhil supervisor, Dr René Bañares-Alcántara, for his support, guidance and care over the past four years. As a great academic, René has managed to channel my energy and eagerness for research in the right direction and pushed me to the limit to achieve my potential while giving me the freedom to find the ways that worked best for me. René is not just a great supervisor, he is a great human being and someone I will be proud to call my mentor for the rest of my life and go back to for wisdom, support and balanced and unbiased opinions.

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List of Abbreviations

AAAS	American Association for the Advancement of Science
AHP	Analytical Hierarchical Process
CBA	Cost-Benefit Analysis
CNM	Clauset, Newman and Moore community structure analysis algorithm
DSS	Decision Support System
GIS	Geographical Information Systems
GraphViz	Graph Visualization Software
GUI	Graphical User Interface
ID	Identifier
IEEE	Institute of Electrical and Electronics Engineers
MCDA	Multi-Criteria Decision Analysis
MCS	Monte Carlo Simulation
OPTIC	Optimal Policies for Transport in Combination
PM	Policy Measure
SMART	Simple Multi-Attribute Rating Technique
VIBAT	Visioning and Backcasting for UK Transport Policy

Chapter 1

Introduction

1.1. Introduction

Since the 1950s, engineers have slowly started to participate in policy issues. One of the earliest examples dates back to 1949, when Phillips (1950), an engineer turned economist, invented the Phillips machine for modelling the British economy. The machine was designed to understand the circulation of money in the economy and the experiment illustrated the intricacies of synchronizing fiscal and monetary policy (control of tax and spending vs. control of interest rates). In the late 1950s, Forrester (1957, 1958) started applying engineering ideas and computer technology to the study of industrial production and society in general, to generate insights and to design and test policies that improved performance and robustness.

Ever since the pioneering research by Phillips and Forrester, involvement by engineers in policy issues has gradually increased. Engineers have started to apply engineering

methodology and ideas to policy problems. For example, Fiddaman (1997, 2002) conducted research exploring policy options and modelling techno-economic systems. Another crucial factor contributing to this phenomenon was the rapid advancement of science and the increased pressure on policy-makers to regulate technology (e.g. telecommunications, biotechnology, web security and privacy issues). Policy-makers could not independently gain deep understanding of such complex domains and called on scientists and engineers for advice and support. Such demands resulted in the formation of policy committees in engineering professional associations. For instance, in response to the growing involvement of engineers in health care-related issues (e.g. biotechnology and biomedical engineering) and to provide technical solutions and assist in the formulation of healthcare policy and regulations, the Institute of Electrical and Electronics Engineers (IEEE) established the Health Care Engineering Policy Committee (Bronzino, 1987).

Despite such developments, even 10 to 15 years ago the involvement of engineers in policy-related issues was seen as a niche activity and was often not taken seriously by the majority of engineering professionals. However, it is increasingly understood that the development of technical artefacts and social arrangements are closely interdependent, and in order to be successful in tackling complex problems their design and analysis has to be carried out together (Bauer and Herder, 2009). Traditionally, there has been a deep divide between technical and social scientists (Johnson, 2008; Wilbanks and Lee, 1985) and there is a general perception among them that they address different problems. Furthermore, they use different vocabularies and often have lack of interest and/or trust in the abilities of each other in addressing the problems we face.

Fortunately, with the increase in our understanding of the complex interactions between technical and social systems over the years, and due to the increasing level of attention

and interest in concepts such as sustainability, which cannot be completely satisfied within just one of these domains, perceptions are gradually changing. Consequently, the involvement of engineers in policy-related issues has been growing at a much higher rate since the late 1990s. Darton (2003), for instance, stated “We must be able to measure sustainability in order to check whether a new policy or decision or technical innovation is making things better or worse.” Such a statement recognizes the effects of policy alongside technical solutions on sustainability assessment in energy- and environment-related issues.

Tackling problems as complicated as climate change, which are dependent on various technical, cultural and geographical constraints, relies on the development of mutually reinforced and integrated policies that create synergies and avoid contradictions. There has been a rapid growth in the involvement of engineers in dealing with technical aspects/issues in policy relating to, for example, the environment (Malcolm et al., 2006), sustainability (Cannon, 2004), and infrastructure (Johnson, 2007, Fassio et al, 2005). Such efforts have already resulted in the inclusion of public policy in the curriculum of some engineering departments (e.g. Fisk and Ahearn, 2006) and the establishment of energy and public policy programmes such as the Engineering and Public Policy Department at the College of Engineering at Carnegie Mellon University or the ArcelorMittal Dofasco Centre for Engineering and Public Policy at McMaster University (for a comprehensive list see AAAS, 2011).

While maintaining their traditional role in the development and improvement of products and technologies and the minimization of costs and risks associated with them, engineers are increasingly becoming aware of the potential role they could *directly* play in policy-making. While advocating the engineer’s role in public policy, Galloway (2004) states that “over the years, engineers have simply not recognized the direct link of the public policy process to ethical and moral role and responsibility to protect the

health, safety and welfare of the public” as part of their code of ethics in their professional organizations. Engineers should advocate feasible solutions to the problems faced by society and should maximize public welfare and minimize negative impacts; these opportunities will be missed if engineers continue their traditional non-involvement in politics (Galloway, 2004).

Engineers are increasingly becoming involved in supporting the development of solutions to address the complex problems we are facing, and are therefore changing their traditional attitude of just focusing on providing technical solutions. For instance, a recent role has been contribution to formulation of UK energy policy (Clift, 2006). Banares-Alcantara (2010) suggests, “new future roles [for engineers] will be as providers of tools, methods and systems to support formulation, management and enforcement of policies”. He provides a number of justifications as to why it is desirable for engineers to get more involved and further develop their capacity in this new role. Taeihagh et al. (2009a) emphasises the provision of methods, tools and systems that are fundamentally different from tools commonly used in policy formulation, with the intent to assist (not replace) policy-makers and complement (not substitute or compete with) existing mathematical modelling tools.

1.2. Objectives and Contributions

The purpose of this research is to develop methodologies and support tools to facilitate better design and formulation of policies by using knowledge gained in other fields that address design issues, mainly process design and synthesis. A new framework for and a systematic approach to the formulation of policies is proposed. Focus has been directed to the interactions between policy measures, inspired by the concepts in process design and network analysis. In addition, an agent-based modelling (ABM) approach has been developed to create a virtual environment for the exploration and analysis of different

configurations of policy measures in order to build policy packages and test the effects of changes and uncertainties while formulating policies. The agent-based approach utilizes techniques such as conceptual design, network analysis and multiple criteria decision analysis (MCDA).

By developing systematic approaches for the formulation and analysis of policies it is possible to analyse different alternatives in greater depth, examine more alternatives, decrease the time required for the overall analysis, provide real-time assessment and feedback to the domain experts on the effect of changes in the configurations, and ultimately form more effective policies with synergistic and reinforcing attributes while avoiding internal contradictions. As a proof of concept, the framework and methodologies introduced are implemented as case studies on the design and formulation of policies to deal with transportation issues. These include the promotion of walking and cycling and emission reduction. In particular, the use of the framework and the support system is intended to help decision-makers and policy experts in selecting appropriate policy measures to form policies for achieving their objectives in each case study.

This research constitutes the first step towards the development of a general family of computer-based systems that support the design of policies – not only for the transport sector, but also for areas such as energy, biofuels, food security, water, health, etc. The new approach is intended to assist (not replace) transport policy-makers, and complement (not substitute nor compete with) existing mathematical modelling tools. It should be emphasised that the decision support system (DSS) described in this document is intended for the generation of different alternatives and their initial screening and not for their evaluation (e.g. via simulation).

The key contributions of the thesis are:

a) A fresh contribution to the methodological development of policies and demonstration of the usefulness of computational approaches in addressing the complexity inherent in the formulation of policies.

b) Development of a new framework for policy formulation which has the potential to:

(i) Accelerate the design of new policies and the update of existing ones;

(ii) Improve the chance of policy success through the exploration of more alternatives; and

(iii) Facilitate the specialization of transport policies for different regions and points in time.

(c) Application and integration of network analysis techniques for improved visualization and ranking of policy measures in the policy formulation process.

(d) Development of a more holistic approach to improve the quantitative assessment of the merits of policy measures and packages, considering not only their internal properties but also their interactions.

(e) Development of a novel ABM approach for the formulation of policies based on the proposed framework that:

(i) integrates the results from network analysis and policy ranking;

(ii) provides a virtual environment for the exploration and analysis of different configurations of policy measures in order to build policy packages; and

(iii) tests the effects of changes and uncertainties while formulating policies.

The ideas and methodologies have already created interest among policy experts and have been adopted in the ongoing EU project “Optimal Policies for Transport in Combination” (OPTIC, 2010), as well as in the “Visions of the Role of Walking and Cycling in the 2030” EPSRC research project (Tight et al., 2011). Aside from creating interest among policy experts and academics, the methodologies have created interest

among practitioners e.g. Reading Borough Council in their analysis for the development of their Local Strategic Transport Plans.

1.3. Structure of the Thesis

In this thesis, we will introduce relevant concepts relating to policy and policy design, followed by introducing the work that has been carried out on the development of a new policy formulation framework. The framework and methodologies developed are then applied in two case studies for proof of concept. Furthermore, the methodologies and the results from the case studies are used for the development of support systems in the formulation of policies and applied to the second case study on the promotion of walking and cycling. Figure 1-1 shows a road map for the structure of the thesis.

Chapter 2 provides background information on policy design and the policy process, presenting some of the approaches taken in simulation and modelling in the transport sector. Moreover, problems faced in the formulation of policies and the similarities between policy design and engineering design (especially process design and synthesis) are highlighted in this chapter.

The details of our proposed framework for policy formulation are presented in Chapter 3. The backcasting approach and some of the details of the Visioning and Backcasting for UK Transport Policy (VIBAT) project, which inspired us to develop the framework, are also introduced in this chapter, as well as some of the terminology used in the thesis.

In Chapter 4, we focus on the formulation of policy packages. An overview of the use of networks and MCDA in policy-making is provided. We provide details of our policy measure analysis approach through the definition, classification and storage of different

relation types among policy measures, highlighting how this information can be used in different visualizations and analyses of the policy measures.

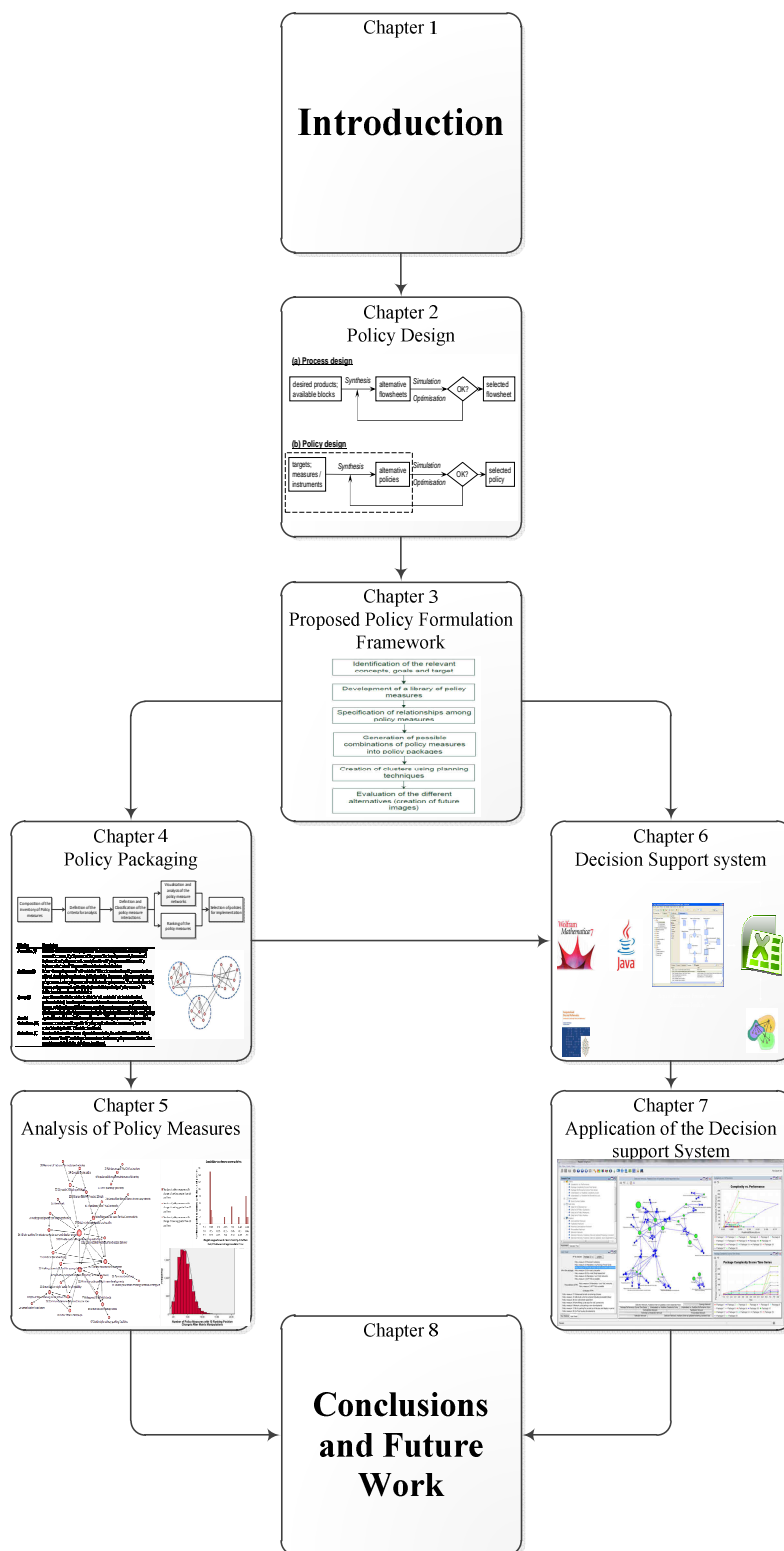


Figure 1-1 Thesis roadmap

Chapter 5 showcases the application of the framework and methodologies developed and discussed in chapters 3 and 4 on two case studies (UK transport-emission reduction and the promotion of walking and cycling in cities). Each case study contains an introduction to the particular problem it addresses, followed by the implementation details. Results and discussion of the application of assessment and visualization methodologies are presented, followed by the conclusions reached in each case.

In Chapter 6, the development of an agent-based policy formulation methodology is discussed. An overview of the ABM paradigm is presented, followed by the objectives of using such an approach for policy formulation and details of the system architecture. A conceptual framework and the details of implementation of the system based on the framework and the methodologies discussed in chapters 3 and 4 are presented. Furthermore, the roles that different agents and processes play are illustrated. Finally, the importance and some of the details of the use of visualizations and the graphical user interface (GUI) for supporting policy-makers is discussed

The application of an agent-based approach in the formulation of policy packages for the promotion of walking and cycling in cities is presented in Chapter 7. Implementation details and the data used are illustrated, followed by the results achieved from the implementation. The advantages of using an agent-based system in the development of policy packages are presented and the conclusions reached are discussed.

Based on the work discussed in the previous chapters, the thesis concludes in Chapter 8 with a critical discussion on the limitation of the work and recommendations for its further improvement and the extension and enhancement of the result achieved.

1.4. Conference and Journal Publications and Collaborations

Conference Papers

The research presented in this thesis led to the following conference papers:

1. Araz Taeihagh, René Bañares-Alcántara & Moshe Givoni, 'Application of an Agent-Based System as a Virtual Environment for the Formulation of Policies', Energy & People: Futures, Complexity & Challenges, Sept. 2011.
(Chapters 6 and 7)
2. Araz Taeihagh, Moshe Givoni and René Bañares-Alcántara, 'Formulating a Policy Package: What to Start With? A New Technique for the Ranking of Policy Measures', Universities' Transport Study Group (UTSG) conference in Milton-Keynes, UK, January 2011.
(Chapters 4 and 5)
3. Araz Taeihagh and René Bañares-Alcántara, 2010, 'A Case Study in the Application of an Agent-Based Approach in the Formulation of Policies for UK Transport Emission Reduction', European Conference on Complex Systems (ECCS2010), Lisbon University Institute, Portugal, Sept. 2010. (Special mentions for remarkable overall quality).
(Chapter 6)
Video: <http://www.assystcomplexity.eu/video.jsp?video=114>
4. Araz Taeihagh, René Bañares-Alcántara and Zun Wang, 2010, 'Exploring the Potential of Relations in Policy Formulation: A Case for Application of Network

Analysis', European Conference on Complex Systems (ECCS2010), Lisbon University Institute, Portugal, Sept. 2010.

(Chapter 4 and 5)

5. Araz Taeihagh, Zun Wang and René Bañares-Alcántara and, 'Why Conceptual Design Matters in Policy Formulation: A Case for an Integrated Use of Complexity Science and Engineering Design', European Conference on Complex Systems (ECCS2009), University of Warwick, UK, Sept. 2009.

(Chapters 2 and 3)

6. Araz Taeihagh, René Bañares-Alcántara and Zun Wang, 2009, 'A Novel Approach to Policy Design Using Process Design Principles', *Computer Aided Chemical Engineering*, 27, p2049-2054, doi: 10.1016/S1570-7946(09)70732-1. (Chapter

Chapter 2 and 3)

7. Aidid Chee Tahir, Julian Hunt, Araz Taeihagh, Rene Bañares-Alcántara, 'Tools to Support the Development of Energy-related Policies', *Oxford Energy Futures*, 12 June 2009 (Poster Presentation). (Chapter 3)

Journal Papers

The research presented in this thesis also led to the following journal papers:

1. Araz Taeihagh, René Bañares-Alcántara and Claire Millican, 'Development of a Novel Framework for the Design of Transport Policies to Achieve Environmental Targets', *Computers and Chemical Engineering*, 2009, doi:10.1016/j.compchemeng.2009.01.010.

(Chapters 2 and 3)

2. Araz Taeihagh, Moshe Givoni and René Bañares-Alcántara. 'Formulating a Policy Package: A New Technique for the Ranking of Policy Measures', Environment and Planning B, March 2011 (Under Review).
(Chapters 4 and 5)
3. Araz Taeihagh, René Bañares-Alcántara and Zun Wang, 'Network Analysis as a Tool for Policy Formulation: A Case Study on Transport Emission Reduction Policies' Advanced Engineering Informatics, July 2011 (Under Review).
(Chapters 4 and 5)
4. Araz Taeihagh, René Bañares-Alcántara and Moshe Givoni, 'Agent-Based Systems as E-Laboratories for Design and Formulation of Policies', Science, (In preparation).
(Chapters 6 and 7)

Invited Presentations

- Araz Taeihagh, 'A novel approach to policy formulation: an integrated application of complexity science and engineering design', Transport Studies Unit, Oxford University Centre for Environment, University of Oxford, Jan. 2010.

Workshops¹:

- Moshe Givoni, Araz Taeihagh and René Bañares-Alcántara, "Which policy first? A new technique for the ranking of policy measures", Vision2030 Work Package 6, Oxford, 6 September 2010.

¹ Also see Appendix A.11

- Moshe Givoni, Araz Taeihagh and René Bañares-Alcántara, “Building a Policy Package: Advancing Walking and Cycling in Cities”, Helsinki Summer School in Transportation, 8-12 August 2011.
- Araz Taeihagh, James Macmillen, Moshe Givoni, René Bañares-Alcántara, “Policy packaging workshop”, Reading Borough Council, 15 September 2011.
- Araz Taeihagh, Moshe Givoni and René Bañares-Alcántara, “Which Policy First? Applying Network Theory To Policy Analysis”, Nectar Cluster 1 Workshop in Angra Do Heroismo, Crucial Networks For Peripheral Territories, University of Azores, Portugal, 16-17 September 2011.

Collaborations

Collaboration with the following groups and projects also took place:

- Transport Studies Unit, School of Geography and Environment, University of Oxford
- Visioning and Backcasting for Transport Policy in London (VIBAT, 2008) Project
- Optimal Policies for Transport in Combination OPTIC (2010) EU Project
- Visions of the Role of Walking and Cycling in 2030 EPSRC project (Tight et al., 2011)
- Reading Borough Council’s Local Transport Plan (LTP) 2011-2026 Team.

Other Dissemination Efforts

Presentations and lectures based on this work were also given by Dr. Banares-Alcantara and Dr. Givoni at:

- “Design and Integration of Policies to Achieve Environmental Targets”, The 18th European Symposium on Computer Aided Process Engineering (ESCAPE 18), Lyon, France, from 1-4 June 2008.
- “Synthesis of environmental policies: application of engineering methods in the social sciences”, The Mexican Institute of Chemical Engineers Conference (IMIQC), May 2008.
- “Policy Packaging as a tool to improve efficiency of policy making”, Helsinki Summer School in Transportation: Reason Building for Decision-Making in the Transport Sector, Helsinki, 7-11 June 2010.
- “From individual policies to Policy Packaging”, European Transport Conference (ETC), 11-13 October 2010, Glasgow, Scotland.
- “Why and how to move forward: Evaluating the Visions and making policy choices”, Vision2030 Advisory Committee meeting, London, 25th March 2011.
- “Formulation and evaluation of policies”, New College Florida, USA, 20 April 2011.
- “Advancing Walking and Cycling in Cities A methodology to support policy choices”, Reading Borough Council, 7 July 2011.
- “Strategic Policy Packaging in Transport Policy A European Perspective.”, Helsinki Summer School in Transportation, Helsinki 8-12 August 2011.
- “Formulation and evaluation of policies: a systems approach”, Department of Environmental Engineering, Peking University (PKU), China, 5 September 2011.

Chapter 2

Background to Policy Design

2.1. Introduction

There is a consensus in the scientific community recognizing the effect of man-made emissions on the climate and acknowledging the importance and urgency of tackling climate change to avoid catastrophic consequences. A delay in addressing the issue will result in costlier solutions that may not be as effective or even be too late. In 2007, the Intergovernmental Panel on Climate Change's (IPCC) third working group published an assessment report on climate-change mitigation (IPCC, 2007); however, as the recent failure of the first phase of EU Emission Trading Scheme shows, the know-how of effective and acceptable policy development has yet to be attained. Addressing such a complex problem requires the formulation of integrated policies that are coordinated and reciprocally reinforcing.

Targets for reduction of the greenhouse gases emissions are being set by different governments and organizations to stabilize their concentrations. The UK published the Climate Change Bill in March 2007 (DEFRA, 2007; DEFRA, 2008), introducing a long-term and binding target of a 60% reduction in the UK's carbon emissions by the year 2050 in comparison to their levels in 1990. Once these targets are set, various alternatives are conceivable for achieving them.

Banares-Alcantara (2007) points out that the precise nature and scope of policies designed to achieve environmental targets are necessarily geographically and culturally dependent, given the variability of resources, access to technology and political constraints at different locations and times. For this reason, a one-size-fits-all, static policy is unlikely to achieve the desired targets and the need for bespoke policies able to accommodate periodic revisions is now widely recognized. Alternative policies can have different performances in terms of their costs, effectiveness, public acceptance, levels of risk and complexity. Even for a fixed time and place, the identification of a suite of alternative policies (rather than a single "optimal" one), together with clear indications of their trade-offs, is crucial in accommodating the diversity of the stakeholders' preferences.

The introduction of a systematic approach for exploring alternative policies using a computational methodology will accelerate and improve the process of policy-making. Based on the visioning and backcasting approach (Banister and Hickman, 2006a), a new framework for policy formulation has been developed. For proof of concept, the framework and methodologies introduced are implemented as case studies on the formulation of policies to deal with transportation issues, such as the promotion of walking and cycling and emission reduction. These have been used for the development of a DSS that aids the development of policies. The goal is to accelerate the task of policy-making and improve the effectiveness of the policies. The transport

sector has been chosen for the case studies because it is the second-fastest growing source of greenhouse emissions (IPCC, 2007) and due to access to experts in this domain.

The problems faced during formulation of policies can be illustrated by an example. In the context of transportation for instance, for reducing overall automotive emissions, different measures such as increasing vehicle efficiencies, decreasing vehicle usage or a combination of these measures can be employed. However, these alternatives are not equal in their associated cost and required implementation time or level of public acceptability or institutional complexities. As stated by Banares-Alcantara (2007), for instance, “the public may be initially more inclined to rely on a technological improvement of car efficiencies rather than giving up car usage; but in fact, as the Khazzoom-Brookes postulate states, an increase in energy efficiency may lead to increased overall energy use (Khazzoom, 1980), unless the appropriate government policies are put in place.”

In Section 2.2, background information about policy design and the policy process is presented. Section 2.3 details some of the approaches taken in simulation and modelling in the transport sector. Section 2.4 discusses the problems faced in the formulation of policies and Section 2.5 showcases the similarities between policy design and engineering design, especially process design and synthesis.

2.2. Policy and Policy Process

The following complementary definitions of policy are adopted in this thesis:

- A policy is a principle or guideline for action in a specific everyday-world context (Pohl, 2008).
- A policy is a purposeful connection of ends with means (Fenna, 1998).

As stated by Banares-Alcantara (2010), the use of systems theory for the explanation of political processes goes back to 1965 when Easton (1965) defined the function of the political system as the conversion of inputs (political demands and public support) to outputs (decisions and actions) (Figure 2-1(a)). Palmer (1997) extended the idea to explain policies. In this case, policies are systems with interacting parts in which inputs are policy measures (also known as policy instruments) that result in a set of desired outcomes as outputs (Figure 2-1(b)).

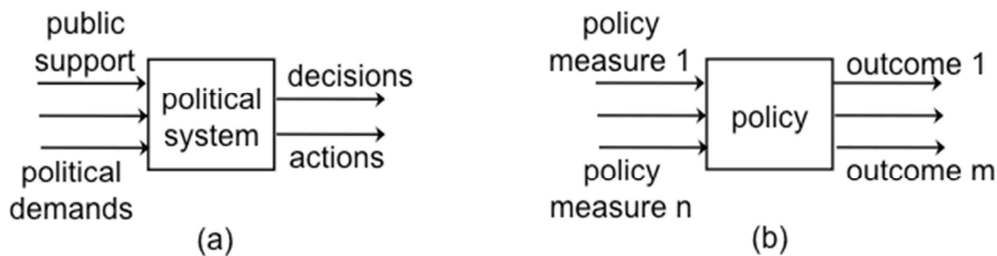


Figure 2-1 Systems theory view of policy cycles (a) and policies (b) (Banares-Alcantara, 2010)

The policy process (also known as the policy cycle) is a process in which a sequence of steps are performed: the setting of an agenda, definition of a problem, development, analysis and refinement of alternative policies to address the problem, selection of a policy as solution, and implementation, enforcement and evaluation of it in a cyclic fashion (Stone, 1988). Figure 2-2 shows a model of the policy process and the context of the policy design step, a step whereby the components of a policy are selected and the overall policy formulated. As can be seen in this figure, the policy process is similar to many engineering systems that have feedback loops or cycles. The policy design and formulation step is the focus of this thesis and is very similar to conceptual design in chemical engineering, a similarity which will be explored in more detail in Section 2.5.

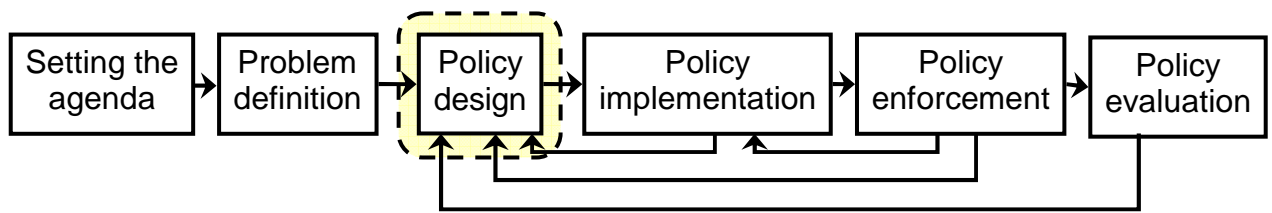


Figure 2-2 A model of the policy process (Taeihagh et al. 2009a), based on (Howlett and Ramesh, 1995)

At present, policy development is done manually. Policies may have various objectives and may be related to technological, economic, social and political aspects. Simulation tools and complex models such as MARKAL (Seebregts et al., 2001) focus on mathematical modelling of these technological and economic factors. However, although mathematical models provide valuable insights, they are only part of the required inputs to a general policy-making process, because decisions about desirable futures, and the policies to attain them, are essentially a question of social values and political choice (Robinson, et al. 2006). Moreover, because of diverse objectives and interests of the stakeholders involved, they attach different preferences to the alternative solutions (Stirling, 2003).

2.3. Simulation and Evaluation of Policies in the Transport Sector

The focus in the literature within the transport domain has been on the development of mathematical models and tools for the assessment of large-scale infrastructure projects and analysis of transport policies. Monetary-based techniques (e.g. Cost-Benefit Analysis (CBA)) and MCDA techniques such as the Analytical Hierarchical Process (AHP (Saaty, 1990)) and the Simple Multi-Attribute Rating Technique (SMART (Edwards, 1977))) form the basis of the models and tools. Often, risk analysis techniques and probabilistic models (e.g. Monte Carlo Simulation (MCS)) are used to further refine and fine-tune the models. The majority of the DSS used in the transport

sector use combinations of the above-mentioned techniques and focus on the evaluation and optimization of different alternatives. There are:

- Generic systems, such as HUGIN EXPERT (which utilizes Bayesian Networks and Influence Diagrams) (Madsen et al., 2003), Expert Choice (which utilizes AHP), and Criterium DecisionPlus (which uses AHP and SMART);
- Purpose-built systems for the transport domain, such as an infrastructure investment prioritising tool (Tsamboulas and Mikroudis, 2006), CLG-DSS (Salling et al., 2007), CBA-DK (Salling and Leleur, 2006), COSIMA-DSS (Salling et al., 2005), SMILE (Tavasszy et al., 1998), and the multi-criteria evaluation of transport options method (Sayers et al., 2003); and
- Geographical Information Systems (GIS) (Arampatzis et al., 2004; Symeonidis et al., 2004).

A similar trend can be seen with large-scale European projects that relate to transport policy and use of DSSs. The main focus, very similar to the development of DSSs, is directed towards the evaluation of policies. The projects and the issues they address are:

- (a) EVA-TREN (2008): Developing appraisal methods for large infrastructure projects and the suggestion of best practices and systematic methods for in-depth comparison of the projects.
- (b) SPOTLIGHTS (2002): Providing access and integrating existing databases and evaluation models.
- (c) LOGIQ (2000): Identifying actors in the decision-making process and providing them with information regarding intermodal transport.
- (d) SPIN (2003): Providing statistical data for analysis of geo-referenced data and the development of a Spatial Data-Mining System.

(e) STEEDS (Brand et al., 2002): Developing a DSS for exploring the influences of the market on technological development and energy and their environmental impact (based on the NAIADe methodology (Munda, 1995)).

2.4. Problems of Policy Formulation

Both in the case of policy design in general and in the transport sector specifically, decisions about what to include in policies (their synthesis) is done manually. This, together with the size of the space of possible policies, results in a large portion of the design space being left unexplored (Banares-Alcantara, 2007). New options are made available for a variety of reasons, such as the introduction of new technologies, the rapid advancement of current technologies and an increased level of complexity in socio-technical systems. The latter is a consequence of issues such as globalization and increases in the power of multinational corporations, demand for energy, and environmental constraints (both intentional – such as health and safety standards – and unintentional, e.g. global warming).

We believe a systematic approach to explore the space of alternative policies using a computational methodology will accelerate the task of policy-making and improve policy effectiveness (Taeihagh et al., 2009a).

2.5. Process Design and Policy Design

The design of different products and processes requires the development and use of various kinds of knowledge and techniques that can also be useful for development of methodologies and tools for policy design. In policy formulation, first a set of alternative options is generated (synthesised) and then often analysed via simulation and optimization of the alternatives in order to select the most appropriate courses of action.

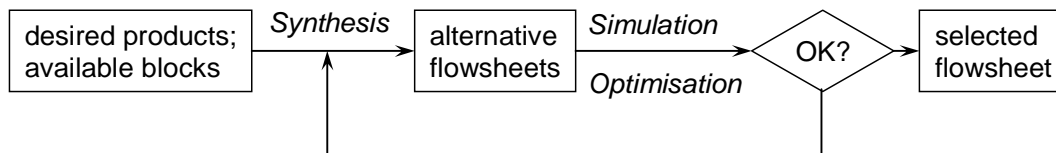
The synthesis of the policies is carried out by a combination of a number of policy measures as building blocks, taking into account the characteristics of the policy measures and with the aim of reaching a desired target. However, optimization-based approaches have difficulty in dealing with ‘wicked’ problems (Rittel and Webber, 1973).

Similar to the policy domain and to the transport section specifically, there are powerful simulators used for chemical process design (Finlayson, 2006), such as ASPEN Plus (2008), HYSYS (2008), and PRO/II (2008). Westerberg (2004) defines process synthesis as the invention of a structure and its associated operating conditions for a new process and, in contrast to the policy domain, process engineers have developed a set of tried-and-tested synthesis methods that help in the selection of the items of equipment and how they are to be interconnected in a flowsheet structure. This invention of structure often requires discovery of the best configuration of equipment from a very large number of possible alternatives.

In process design, “synthesis and simulation steps are applied in tandem and iteratively: a synthesis step generates alternative designs and the output from a simulation step is used to compare those alternatives and inform the application of the next synthesis step” (Banares-Alcantara (2007), see Figure 2-3(a)). The introduction of the aforementioned techniques radically changed the way in which chemical processes were designed.

In this thesis, the focus is on adaption/adoption of existing process design methods and the development of new techniques and methodologies for the design of policies. The intention is to provide practical frameworks and tools for supporting the selection of best policy measures and the most effective combinations of them into packages for better policy formulation (the set of tasks included inside the dashed box in Figure 2-3(b)).

(a) Process design



(b) Policy design

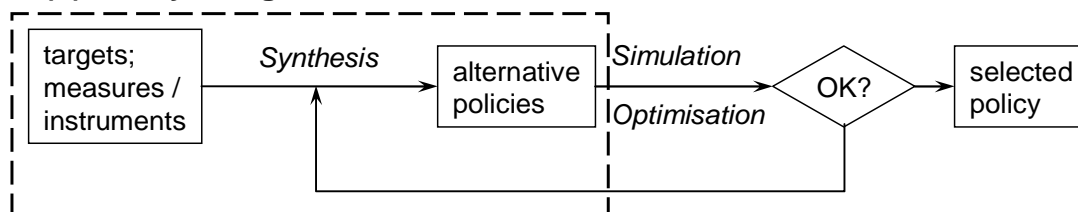


Figure 2-3 Analogy between (a) process design (adapted from Westerberg (1981) and (b) policy design (Banares-Alcantara, 2007)

In both policy design and process design, there is no prior agreement on the criteria or preferences to use; in fact, both are co-evolutions between the desirable results and possible solutions in a cyclic fashion as shown in Figure 2-3. In short, there are no unique optimum policies, just satisfying ones (Simon, 1996). The following two concepts become important to understand the nature of policy and process design:

- The exploration-based model of design (Smithers and Troxell, 1990), which understands design as an ill-structured problem where the design goals and the designed artefact evolve in a single front because a complete specification of the design objectives is not available at the outset of the design process.
- The use of a hierarchical organization, which makes the analysis, understanding, description and development of systems easier than for non-hierarchical structures, due to their decomposability (Simon, 1996).

Both of these concepts are reflected in the Hierarchical Design Method (Douglas, 1988) and have been adopted in DSSs such as n-Dim (Westerberg et al., 1993), KBDS (Banares-Alcantara and Lababidi, 1995) and Improve (Marquardt and Nagl, 2004).

Our hypothesis is that the process by which the collection of operators is synthesised is similar. However, different approaches (and a certain degree of adaptation of process synthesis techniques) will have to be employed for considering the differences between policy and process design, especially the non-quantifiable factors in policy-making.

2.6. Summary

In this chapter, background information about policy design and the policy process were presented. As the transport sector is the focus of the case studies carried out for this thesis, some of the approaches taken in simulation and modelling in the transport sector have been presented. Moreover, the problems faced in the formulation of policies, and the similarities between policy design and engineering design (especially process design and synthesis) have been discussed and highlighted in this chapter.

Chapter 3

Proposed Policy Formulation

Framework

3.1. Introduction

Inspired by a normative scenario analysis known as the visioning and backcasting approach (Banister and Hickman, 2006a), a new framework for policy formulation has been developed. Section 3.2 provides a brief description of the backcasting approach and Section 3.3 provides some of the details of the VIBAT project and the specific terminology used throughout the thesis. Section 3.4 introduces the proposed framework for policy formulation and the six steps that constitute it. Section 3.5 briefly provides an overview of the two case studies carried out for proof of concept.

3.2. Backcasting

Robinson (1990) proposed backcasting as a normative scenarios analysis technique for achieving desired end-points. Backcasting works backwards from a desired end-point trying to establish what policies need to be in place in order to reach that desired state. Backcasting is intended to suggest the implications of different futures, based on criteria associated with values and norms such as social and environmental desirability, which is different from the forecasting techniques that try to predict the likelihood of different futures (Robinson, 2003). Given the limitations of current models and the uncertainty in data, forecasting is better suited to addressing short-term solutions (the traditional trend in the transport sector), but problems such as climate-change mitigation and adaptation require long-term planning. Backcasting is useful for addressing highly complex and long-term problems because it has the potential to identify unresolved subproblems and bottlenecks that are critical in the solution of the overall problem. It can thus guide policy-makers as to where action is required and help them in creating solutions that are creative and radically different from the status quo.

3.3. VIBAT

The VIBAT project studied the potential for a 60% reduction of emissions due to transport by the year 2030 through the use of a scenario-building and backcasting approach (Banister and Hickman, 2006a). It consisted of three stages:

- 1 – Setting a 60% reduction target for 2030 and forecasting the business-as-usual scenarios for transportation in the UK and developing a baseline in order to allow assessment of the level of change required for achieving the emissions-reduction target.

2 – Development of transport systems in 2030 that would achieve the reduction target. This was done in form of development of two alternative future images which would push various technological and behavioural options.

3 – Backcasting approach in which alternative policy packages were combined to lead to the future images.

Unlike the traditional forecasting approaches, the VIBAT project considered a 60% reduction target for the year 2030 and proposed backcasting to select policy measures and policies/paths to design a policy. Policy measures were placed in 11 policy packages in VIBAT project with the hope of creating synergies among them (Banister and Hickman, 2006b). The policy packages were then bundled into policy clusters aiming to achieve the emission reduction target.

In summary, the study examined an array of policy measures and considered whether they could be effectively combined in order to reach the target. The goal was to establish whether reaching the target is feasible, identify the difficulties, and the key decisions that need to be taken.

3.3.1. Definition of Terms used in the Development of Policy Hierarchies

The terms ‘policy measure’, ‘policy package’, ‘policy cluster’, ‘future image’ and ‘policy pathway’, which are used in this thesis, are adopted from the VIBAT project. Below, a definition of each term is given and Figure 3-1 illustrates their relation:

- Policy measure (also known as a policy instrument). Combinations of policy measures constitute policies. A policy measure is the building block used for the creation of policy packages, clusters and, ultimately, the future images to reach the

target. A total of 123 policy measures were identified based on various pieces of research (Banister et al., 2000; Marshall and Banister, 2000; VTPI, 2007). Policy measures have been categorized in various forms. Bridgman and Davis (1998) classify policy measures as: (a) exhortation (e.g. education); (b) economic incentives/disincentives (e.g. subsidies and taxes); (c) government provision; and (d) legislation/regulation. Banister and Hickman (2006b) categorize policies as technological, regulatory, economic and social.

- Policy package. Policy packages help in structuring the policy measures by grouping those that are similar, work together, and/or have a synergistic effect. Policy measures are not equivalent in terms of their properties (e.g. cost, effectiveness, risks, etc.) or interactions with other policy measures and levels of dependencies they have. A good policy package is a set of policy measures that creates synergies and avoids contradictions and conflicts or mitigates them, ensuring that the policy will address the problem effectively and equitably over the long term (Badami, 2004). In VIBAT, 11 policy packages were proposed which cover all transportation modes.
- Policy cluster. Clusters are formed based on core packages to which other supporting packages are added. Their purpose is to reach the emissions-reduction target levels for each image (scenario) of the future. There is no claim on the clusters being comprehensive.
- Future image. Each future image is a result of the implementation of one or several policy clusters to reach the emissions-reduction target.
- Policy pathway. The policy pathways indicate the temporal ordering in which certain decisions need to be made. They are useful since, for example, long lead times are required for implementing groundbreaking policies, e.g. introducing

legislation, providing incentives for industries to move towards the target, and changing public attitudes and individual behaviour.

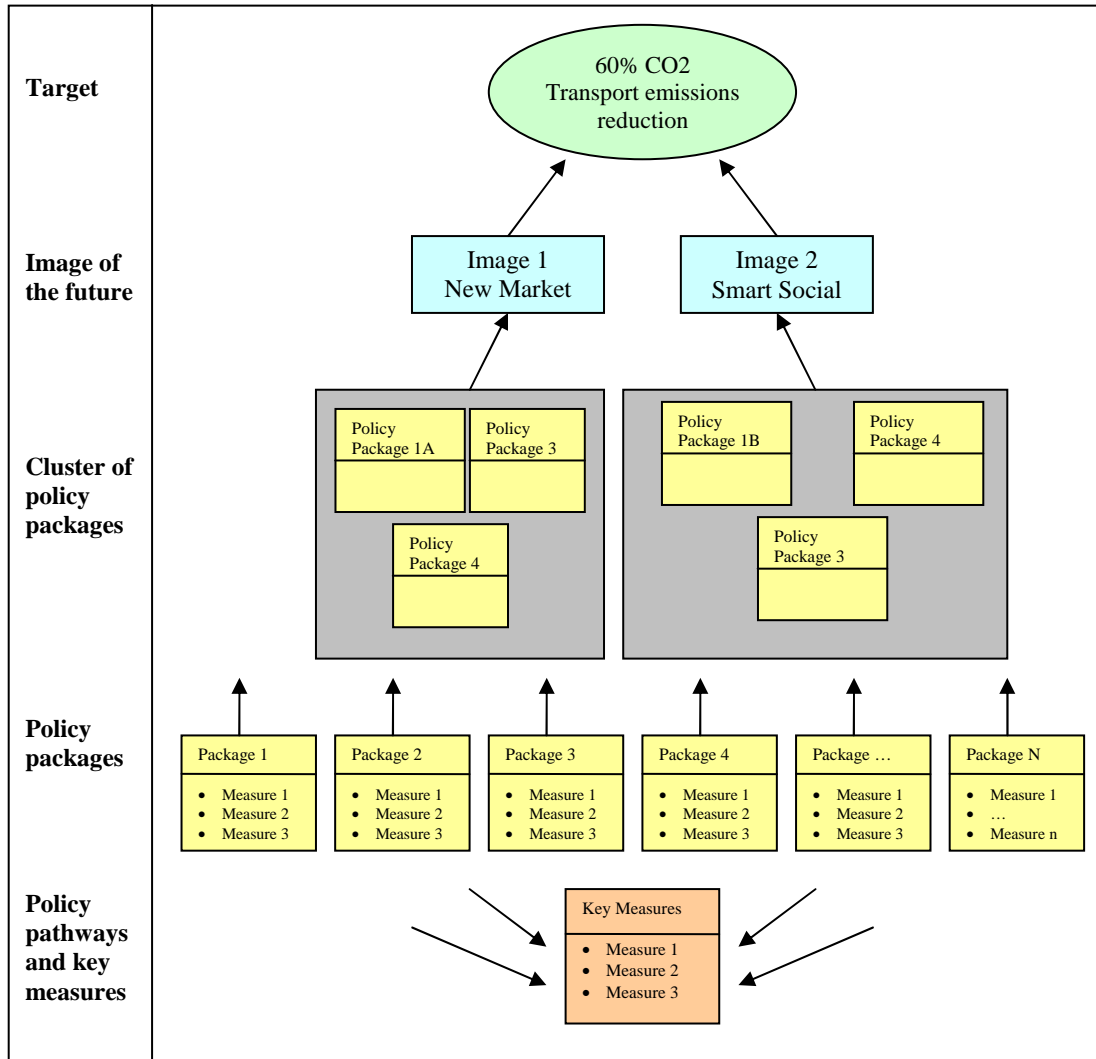


Figure 3-1 Packages, measures and pathways, based on Banister and Hickman (2006b)

3.4. Proposed Framework for Policy Formulation

The proposed policy formulation framework (Taeihagh et al., 2009a) is broken down into six steps (see Figure 3-2).

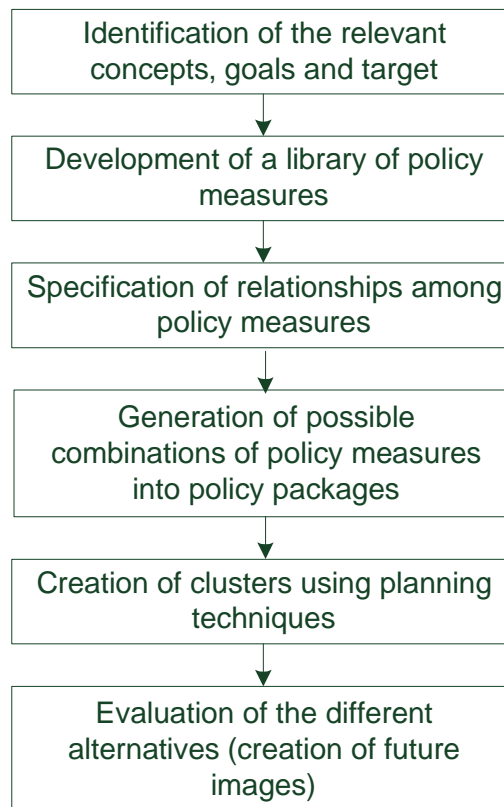


Figure 3-2 Policy formulation process
(Taeihagh et al., 2009a)

3.4.1. Identification of Relevant Concepts

The target has a numerical value relating to a performance metric that is to be attained by a given date, e.g. 60% CO₂ emissions reduction by the year 2030 in the case of the VIBAT project. The terms ‘goal’ and ‘objective’ are used interchangeably, and are the desired results of a strategy. A goal has a more qualitative nature, although associating numerical values is also possible. Achieving a number of goals will facilitate achieving the ultimate desired outcome, which is defined as the target. For instance, the goal can be to avoid or mitigate climate change.

3.4.2. Development of a Library of Policy Measures

The creation of a repository of available measures requires the participation of experts in the field and different stakeholders using available scientific data and reverse-engineered knowledge from existing policies. New measures may be created at any point in time.

Policy measures have very different natures and characteristics. For instance, in the transportation context, they may be economic (e.g. taxation on multiple car ownership), regulatory (e.g. introduction of low emission zones), technological (e.g. introduction of electric cars to the vehicle fleet) or social (e.g. awareness campaigns). Some of the measures are expressed quantitatively, but many have a qualitative nature.

Policy measures have different properties, such as degree of effectiveness, implementation time and costs, levels of technical or institutional complexity, public acceptability, requirements of implementation, targeted objective(s), level of uncertainty, level of risk, associated cost(s), etc. A simplified example of the “hybrid technology vehicles” measure is shown in Figure 3-3.

Policy Measure Name: Hybrid Technology Vehicle
Policy Measure Id: 122
Policy Measure Type: Technological and Economic
Effectiveness: High
Uncertainty: Low
Timescale of Implementation: Long
Cost: Medium
Risk Level: Low
...

Figure 3-3 Example policy measure (Taeihagh et al., 2009a)

3.4.3. Specification of Relations Among Policy Measures

The relations among policy measures are currently categorized as ‘precondition’, ‘facilitation’, ‘synergy’, ‘potential contradiction’ and ‘contradiction’. For instance, a precondition of a policy measure is defined as another measure that is required for successful implementation of a policy measure, which should therefore be implemented earlier. A precondition relation is directional. Each policy measure is depicted as a node and its preconditions as its links. As an example, Figure 3-4 illustrates the preconditions for “Advanced traffic management systems”. Note our convention for the direction of the relation: in this example, the “Advanced traffic management systems” policy measure has the rest of the policy measures as its preconditions. The details of the definition and classification of the policy measure relations are provided in Chapter 4.

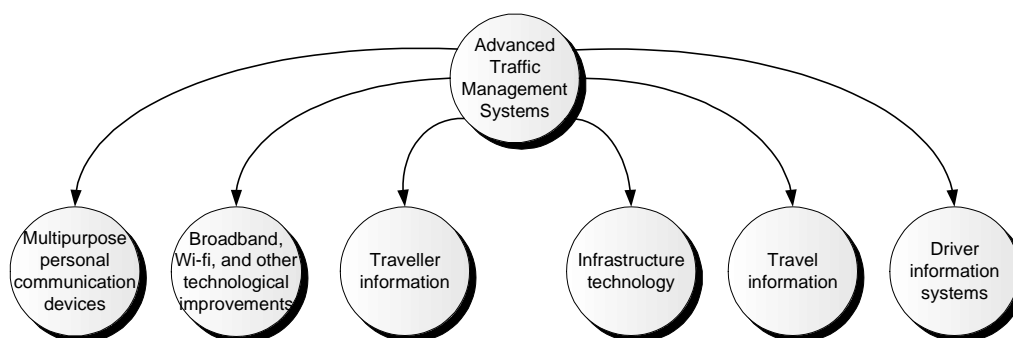


Figure 3-4 Example policy measure and its preconditions

3.4.4. Generation of Policy Packages

In this step, synthesis and configuration techniques are applied to generate alternative combinations of policy measures into packages. For instance, three simple policy measures such as “ban non-hybrid vehicles from ‘green’ areas”, “consumer tax incentives” and “higher fuel taxes” could form a package that encourages public to use “hybrid technology vehicles” (see the lower mid branch in Figure 3-5). The nodes labelled “MIX” in the Figure 3-5 represent that combines the policy measures.

Powerful concepts and methods such as *abstraction/refinement hierarchies* and *Generate&Test* can be utilized for formulating policy packages (see Westerberg (2004) for different techniques used in process synthesis). In addition to the aforementioned techniques, graph theory and network analysis techniques can be used for exploring the relations among different policy measures, in order to better understand the overall effect of the implementation of policy measures on the system and on each other.

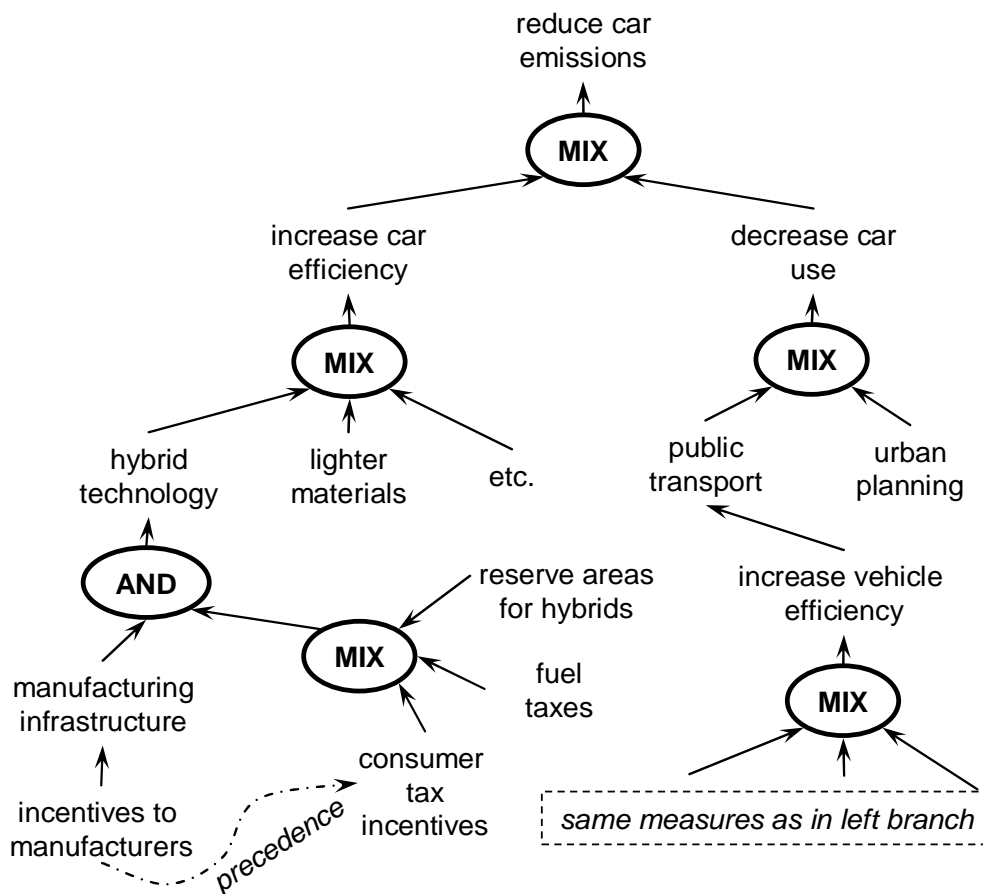


Figure 3-5 A simplified example set of alternative policies (Banares-Alcantara, 2007)

Figure 3-5 represents several alternative policies that all aim at reducing emissions. Such alternatives can be constructed by using the library of policy measures. Furthermore, the alternatives can be assessed with respect to different criteria, and ranked based on their desirability.

3.4.5. Application of Planning Techniques

Going back to the example in Figure 3-5, some “*manufacturing infrastructure*” needed to produce hybrid vehicles will obviously need to be in place before “*hybrid technology vehicles*” become more popular. Similarly, “*incentives to manufacturers*” should precede “*consumer tax incentives*”, and both types of incentives may be decreased gradually as production and consumption increases (not shown in the figure). Temporal aspects should be considered during the formulation of the policy measures into packages. For instance, some of the policy measures have long implementation time, delays before their effects are felt or precondition requirements. Moreover, it is important to consider the effects of decision making on the potential policy measures that are likely to be considered in the future.

3.4.6. Evaluation and Comparison of Alternative Policy Clusters

This step involves evaluation of the alternatives generated and recommendation of the most suitable ones by aiding the user in their comparison. Furthermore, a sensitivity analysis will be employed in order to observe the effects of perturbations on the overall system.

3.5. Application of the Framework

The framework and a set of methodologies based on it (Chapter 4), allowing a systematic approach to the synthesis and configuration of policies, have been implemented in two case studies (Chapter 5). The framework and the methodologies based on it have also been used for the development of a DSS that aids in the development of policies (Chapter 6) and its implementation (Chapter 7). The case

studies focus on the formulation and analysis of policies required for achieving CO₂ emission targets in transport sector and promotion of walking and cycling. The aim behind the development of the framework and the methodologies based upon it is to accelerate the task of policy-making and improve the effectiveness of the policies.

3.6. Summary

The details of our proposed six-step framework for policy formulation and some of the terminology used in the thesis were presented in this chapter. Furthermore, the backcasting approach was introduced, along with some of the details of the VIBAT project which aims at studying the potential for a 60% reduction of emissions due to transport by the year 2030.

Chapter 4

Formulation of Policy Packages

4.1. Introduction

Many ‘policy problems’ are commonly referred to as ‘messy’ (Ney, 2009) or ‘wicked’ (Rittel and Webber, 1973) due to the inherent technical, institutional and political difficulty of addressing them. As understanding of the complexity of policy problems has increased along with wide experience gained in trying to tackle them through various measures, and as knowledge and experience is more easily shared, policy-makers are rarely short of options. Rather, policy-makers more often face the opposite problem of having too many avenues and options to explore.

Considering a rational policy-maker (putting aside the debate raised by Kingdon (1984) on the extent to which policy-making follows a ‘rational’ goal-oriented process), or an analyst advising the political decision-maker on the best strategy to address a policy problem, the number of possible direct actions (policy measures in this thesis) is

considerable. With respect to transport policy, for example, the VIBAT-London study identified over 120 individual measures to combat climate-change challenges in London (Hickman et al., 2009). Similarly, the Policy Scenarios for Sustainable Mobility project (POSSUM - Banister et al., 2000) identified close to 100 measures to advance sustainable transport in Europe and the Visions 2030 project (used as the second case study in this thesis in chapters 5 and 7) identified 142 measures to promote walking and cycling in cities.

Given the variety of options available, the information available on them, and various influences on the policy-makers, the answers to the questions of what to do and what to do first are becoming increasingly complex. Given all of the available information and various options, Kelly et al. (2008) and Jones et al. (2009) point out there is evidence of inertia and insufficient attention and consideration is often given to more than a few options. This problem is more likely not to be due to difficulty in coming up with list of policy measures or ideas for action but due to the difficulty inherent in considering all the options.

Silver bullets do not exist in policy-making and the need to explore and implement a wide range of options to increase the rate of policy success is increasingly being recognized. Instead of implementing individual policy measures, a combination (package) of policies needs to be implemented to ensure the successful and efficient attainment of a given policy objective (May and Roberts, 1995, Banister et al., 2000, Feitelson, 2003). Givoni et al. (2010) define a 'policy package' as "a combination of individual policy measures, aimed at addressing one or more policy goals; a package is created in order to improve the impacts of the individual policy measures, minimize possible negative side-effects, and/or facilitate the interventions' implementation and acceptability". The main thrust behind policy packaging is that more than one policy measure is considered and the relations among the selected policy measures are

explicitly taken into account, with the intention that these policy measures are mutually supportive.

The decision on what to start with in addressing a policy problem or a policy goal is not straightforward. To facilitate this step, a new methodology is proposed to assist policy-makers in exploring a large number of different types of measures simultaneously, while examining both their own properties and their relations with other measures. The methodology is based on the previously proposed six-step policy formulation framework (Taeihagh et al., 2009a) and brings together two established and well-researched concepts: network theory and MCDA. The methodology aims to provide a tool for policy-makers to explore a large number of measures by visualizing and mapping the relations between them and by ranking them. The aim is not to provide a result or suggest a ‘solution’, but only to aid policy-makers in exploring a large field of options and in understanding why certain policy measures appear better than others. The methodology is based on user input (e.g. policy-makers, stakeholders or other experts participating in the policy formulation process) and is generic.

In Section 4.2, an overview of the use of networks and MCDA in policy-making is provided. Section 4.3 provides details of our approach to policy measure analysis by the definition, classification and storage of different relation types among policy measures, and highlighting how this information can be used in different visualizations and analyses of the policy measures.

4.2. Overview of the Use of Networks in Policy- and Decision-Making

Network analysis has been used extensively in the policy domain, for example in social network analysis (e.g. Freeman et al. 1991, Wasserman and Faust 1995), including the examination of policy networks and policy communities (e.g. Rhodes and March,

1992). Social network analysis is an important toolbox for the systematic description and analysis of relational dimensions in politics and society (Schneider, 2005). With recent advances in network science, the use of such techniques is becoming even more widespread (Newman et al., 2006, Milo et al., 2002, Boccaletti et al., 2006).

The policy networks approach is not without its critiques. It has been argued that this approach is only descriptive rather than being explanatory (John, 1998, McPherson and Raab, 1988). Some have considered it a metaphor or a framework rather than a theory (Dowding, 1995, Jenkins-Smith and Sabatier, 1999) and it has been criticized due to lack of attention to the motivating factors that affect the actors (Peters, 1998).

In this thesis, we aim to advance the use of network analysis in policy-making. We are not concerned with a network of actors and the interactions between them, but with the policy measures considered to address a defined policy problem. We are interested in the use of networks as a tool to improve our understanding of the interactions between policy measures and to streamline and improve the policy formulation process. The nature of the relations defined and used in this thesis is fundamentally different from relations in traditional policy networks analysis (examined in detail by Burt (1980) and van Waarden (1992)). Furthermore, we combine the use of policy measure networks with a MCDA approach, to assist policy-makers in examining a wide range of actions and in selecting the measures to implement.

4.2.1. Networks and MCDA

As mentioned above, one of the difficulties in policy formulation is the effective processing of the information available about each individual policy measure, especially in cases where the experts are faced with many policy measures and even a larger number of combinations between them. This problem is exacerbated by considering the

different types of relations that often exist between the policy measures and by time and resources constraints. Such problems can explain the tendency to explore a limited number of alternatives (Kelly et al., 2008, Jones et al., 2009).

CBA and MCDA techniques are commonly used in the policy domain. Often, the merits of the available policy measures are assessed based on a polyvalent set of criteria and their associated weights using MCDA techniques, such as the AHP (Saaty, 1980) or the SMART (Edwards, 1977). General directives and guidelines are available to support such evaluation methods (e.g. Stewart 1992, Guitouni and Martel 1998 and Dodgson et al., 2001). These techniques have also been the traditional techniques used in transport policy decision-making, with a recent shift from CBA to MCDA in Europe (Grant-Muller et al., 2001) and especially in the UK (Glaister, 1999 and Price, 1999).

Some new evaluation techniques have integrated network concepts with multiple criteria decision-making. Examples include the following: a new approach that combines several MCDA methods using network structures (Hanne, 2001); a generic decision-making procedure and framework that integrates Bayesian Belief Networks with MCDA (Fenton and Neil, 2001; Watthayu and Peng, 2004); and the reasoning map concept, which enables multi-criteria evaluation of decision options using causal maps (Montibeller et al., 2005). Importantly, the Analytical Network Process proposed by Saaty (1996) is a general form of AHP geared towards capturing the complexities that arise from the interdependence of the criteria between themselves and vis-à-vis alternatives, rather than towards the multiple forms of interdependence among alternatives. As a result, as the number of elements and their interactions increase, the use of the technique becomes more complex in a nonlinear fashion.

An alternative proposed here is the use of a Network-Centric MCDA approach, which allows policy measures to be ranked based on their internal properties and the

interactions they have with other policy measures. This enables ordinal comparisons (and possibly quantified comparisons as well) between policy measures and, in principle, can also be used to compare between different policy packages. The methodology we propose is described in detail below.

4.3. The Policy Measure Analysis and Ranking Methodology

Faced with a specific (transport) policy problem, policy-makers have many options for action. Below, a methodology is proposed, and later tested, to assist policy-makers to systematically consider and rank a large number of policy measures and identify a measure, or a set of measures, to implement first. The ranking is based on context specific criteria such as the effectiveness of a measure in achieving (part of) the policy target(s), and its efficiency in doing so (accounting for the resources required to implement it), including overcoming different obstacles (financial, technical, acceptability, institutional, etc.). The proposed methodology, and its components and stages, is illustrated in Figure 4-1.

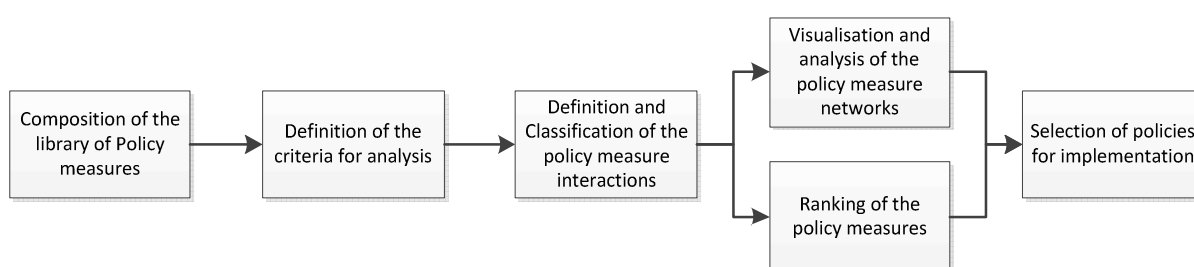


Figure 4-1 The proposed methodology for policy measure analysis and ranking

The first step in the proposed methodology is to draw up a list of measures of various types (infrastructure, regulation, financial, marketing, etc.) that can directly affect the policy target, i.e. a library of primary measures. To fully exploit the benefits of the method it is advantageous to start with a relatively large library. Next, the criteria

against which to examine the measures are decided. As appropriate, given their nature and the information available for the specific circumstances of the policy problem, the criteria can be measured in a quantitative or qualitative manner. After the properties of each measure are assessed by the analyst, they are translated to scores (for example, ranging from 1–low to 5-high). This stage of inputting the basic information for each of the measures in the library completes the preoperational stage. There are no restrictions on expanding the library with additional measures at any stage of the analysis, although naturally this will be more time consuming after the analysis of the initial library begins.

The initial stage above follows standard MCDA practice and indeed can be used to generate a ranking of measures. However, the next steps in the proposed methodology provide additional and crucial information that produce more robust decision-making and different results from those produced by the Traditional MCDA approach.

4.3.1. Definition of Policy Measure Relations

Five types of mutually exclusive relations among policy measures are considered and defined: precondition, facilitation, synergy, potential contradiction and contradiction (Taeihagh et al., 2009b).

Precondition (P) – defined as a relation that is strictly required for the successful implementation of another policy measure. For instance, if policy measure B is a precondition to policy measure A, the successful implementation of policy measure A can only be achieved if policy measure B is successfully implemented beforehand. The precondition relation is a directed relation.

Facilitation (F) – in a case where a policy measure ‘will work better’ if the outcome of another policy measure has been achieved, the relation is considered a facilitation

relation. For instance, policy measure B facilitates policy measure A when policy measure A works better after policy measure B has been implemented; however, policy measure A could be implemented independently of policy measure B. The facilitation relation is also a directed relation.

Synergy (S) – a special case of facilitation relation in which the ‘will work better’ relation is bidirectional (undirected relation). It can be argued that such a relation can be treated as a two-way facilitation; however, we believe treating this relation as a separate type is advantageous, as it suggests the higher effectiveness of both of the policy measures having the synergistic relation vis-à-vis the overall policy.

Potential Contradiction (PC) – a potential contradiction exists between policy measures if the policy measures produce conflicting outcomes or incentives with respect to the policy target under certain circumstances. Therefore, the contradiction is ‘potential’. This relation is undirected.

Contradiction (C) – unlike potential contradiction, which is conditional, the contradiction relation is defined when there are “strictly” conflicting outcomes or incentives between policy measures. Similar to the potential contradiction relation, this relation is undirected.

The classification of the individual relations among pairs of policy measures is carried out by the domain experts (e.g. policy-makers, analysts, etc.) and stored in an adjacency matrix. This task can be done individually or in a group setting. Using a collective decision-making procedure for identifying the relations is advantageous and is likely to increase the robustness of the analysis, since complex relations often exist between the policy measures and, at times, it can be difficult to clearly distinguish the relation type.

Various techniques can be employed to ensure the process is robust and without errors, like using ‘outside the box’ methods as defined by Jones et al. (2009).

4.3.2. Classification and Storage of the Policy Relations

For the storage of the relations among n nodes, an n -by- n adjacency matrix is used. In the adjacency matrix, each element represents a relation between the nodes in the corresponding row and column. In this study, the relations between policy measures (edges) are not weighted, yet this is an option for further development. Initially, a multi-relational adjacency matrix is used for storing the different types of relations among policy measures. The method requires the analysis of only two measures at a time, in total isolation from the other measures in the library, thus simplifying the task for the analyst. Still, when dealing with a large number of policy measures that often have complex relations, it is inevitable that inconsistencies will arise and that in some cases a precise identification of the relation among policy measures will be difficult to determine. For this reason, an iterative approach where at least one iteration is performed for the identification of each type of relation is important for the identification of inconsistencies and errors. The next step, visualization based on the defined interactions (edges) and policy measures (nodes), also serves as a final check on the integrity and validity of the defined relations.

4.3.3. Visualization and Analysis of Policy Measure Relations

Figure 4-2 depicts a sample multi-relational adjacency matrix. An edge exists between nodes a and b if element (a,b) of the adjacency matrix is equal to P, F, S, PC or C, depending on the type of relation between the two nodes. In cases of undirected relations, both elements of (a,b) and (b,a) have the same value.

ID	1	2	3	4
1	0	F	F	S
2	0	0	0	PC
3	0	P	0	P
4	S	PC	0	0

Figure 4-2 Sample multi-relational adjacency matrix

Figure 4-3 below is the visualization of the sample multi-relational adjacency matrix presented in Figure 4-2. In this network, nodes 2 and 3 facilitate node 1, nodes 1 and 4 have a synergistic relation, nodes 2 and 4 potentially contradict each other and nodes 2 and 4 are preconditions for node 3.

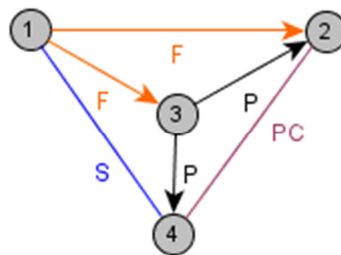


Figure 4-3 Network visualization of the sample data

When dealing with a large network (i.e. a large number of measures), visualization of the data becomes difficult using a single multi-relational network. Therefore, the multi-relational adjacency matrix formed in the previous step is decomposed into individual adjacency matrices that only entail a single type of relation (in our case, five networks corresponding to the five relations defined in Section 4.3.1). Once the separate network visualizations have been checked and the experts involved in the process are satisfied with the data, an analysis of the networks can be performed.

4.3.3.1. Identification of Cycles

Figure 4-4 illustrates an example cycle in a network of policy measures (a Precondition network). In order to favour modern urban design (“new urbanism”) in the

development of cities, a precondition is to move towards clustered land use and providing different functionalities in each district of a city. A prerequisite for such development is the creation of low-emission zones to attract residents to the clusters, which in turn may be achieved by reducing car emissions (e.g. through car-free planning). In order to have successful car-free planning, other means of transportation such as public transport, cycling and walking need to be promoted. In turn, in order to have a successful switch towards the use of bicycles and walking, cities should be compact, so that travel distances are reduced. Lastly, such compact cities can be created by moving towards a new urbanism approach in city planning.

A large number of cycles consisting of five or more policy measure can exist in a policy measure network, as demonstrated by Taeihagh et al. (2009a). Two alternative methods for cycle identification were used. One was to record the list of nodes in a branch when the termination criteria during search was reached due to repetition of a node, indicating the existence of a cycle. In addition, the `Extractcycle` function in the `Combinatorica` package of `Mathematica` (Mathematica, 2008) was used to return a list of maximal edge-disjoint cycles in the network (Pemmaraju and Skiena, 2004).

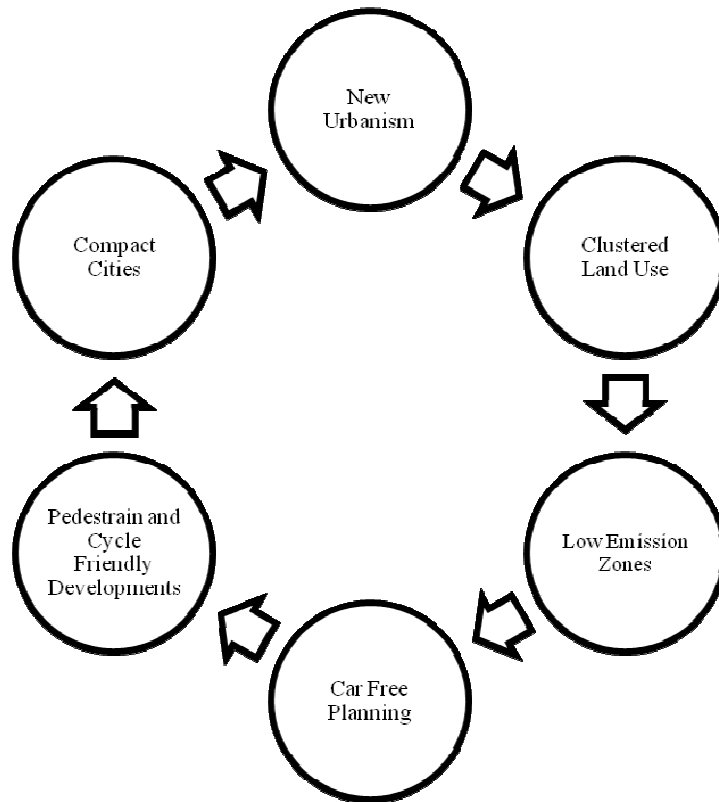


Figure 4-4 Example of a cycle in a policy measure network)

Analysis of the relations between the individual policy measures and their ranking and assessment helps in better understanding the cycles. The knowledge gained through this analysis will be used to break the cycles in the most appropriate manner, leading to a feasible order of implementation for the policy measures with minimal overall cost, implementation time and maximum effectiveness. In the hypothetical situation where all the measures that form a cycle have the same strength, cost, implementation time, risk, etc., the order of implementation does not matter (assuming that the measures do not have relations outside the cycle). However, in a realistic scenario, the degree of importance of the measures, cost, implementation time, etc. differs, and through their appropriate scheduling significant gains can be made.

4.3.3.2. Community Structure Analysis

Community structures often correspond to functional units in networks (Newman, 2004). This method can provide a generic clustering identification technique based on the interactions between policy measures. This aids understanding of the structure of the complex and highly inter-related policy measures used in formulating policies and supports us in selecting more appropriate policy measures.

4.3.3.2.1. The Girvan-Newman Algorithm

The Girvan-Newman algorithm (Newman and Girvan, 2004) is a popular algorithm used for exploring community structures within networks by recognizing that nodes within communities are more densely connected than the inter-community nodes (Figure 4-5). Exploration of the community structures is carried out by calculation of the betweenness² scores for all edges and understanding that inter-community edges have high betweenness values as they create edges between communities of highly connected nodes. The algorithm separates the communities from each other, by removing the edges with high betweenness scores. After each removal, new betweenness scores are recalculated for the remaining edges. Several methods have been developed for calculating betweenness based on geodesic paths, random walks and current flows. Newman and Girvan (2004) illustrated that, in practice, the three methods produce similar results.

Calculation of the betweenness scores and removal of edges in iteration steps is terminated when the optimal community structure is achieved (measured by the modularity Q). Newman and Girvan (2004) define the modularity as:

²Betweenness Centrality is a measure the importance of a node in a network. See Section 4.3.4.1.

$$Q = \sum(e_{ii} - a_i^2) = \text{Trace}(\mathbf{e}) - \|\mathbf{e}^2\| \quad \text{Eq. 4-1}$$

In Eq. 4-1, \mathbf{e} is defined as a k -by- k symmetric matrix of k communities whose element e_{ij} is the fraction of all edges in the network that link vertices in community i to vertices in community j . Element e_{ii} is on the leading diagonal, and a_i is the row sum of the matrix \mathbf{e} (Newman and Girvan (2004)). The trace of this matrix, $\text{Trace}(\mathbf{e}) = \sum e_{ii}$ gives the fraction of edges in the network that connect vertices in the same community. The modularity measures the proportion of the edges that connect same types of nodes in the network (edges within a community), minus the expected value of the community structures with random edges between the nodes. The Q value ranges from 0 to 1, with values typically between 0.3 and 0.7. If the number of edges within communities is similar to random network, Q will be calculated as 0 and in case where there is a strong community structure present Q approaches 1 (Newman and Girvan, 2004).

In non-technical language, the Girvan-Newman algorithm consists of the following steps:

1. Calculation of the betweenness scores based on the geodesic paths method;
2. Identification of the edge with the highest betweenness score and its removal from the network (one edge is chosen at random if there is a tie for the highest score);
3. Recalculation of the betweenness scores for the remaining edges;
4. Repetition from the second step 2 and termination of the iteration loop when an optimal Q value is reached.

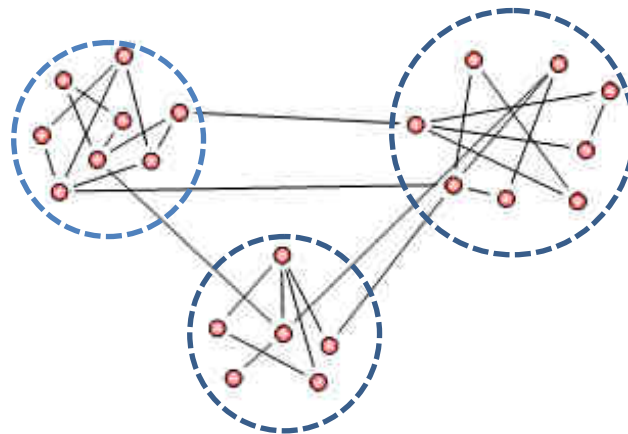


Figure 4-5 An example of a network with three communities, which have dense internal and sparse external connections (based on Newman and Girvan, 2004)

After proposal of the Girvan-Newman algorithm, Clauset, Newman, and Moore proposed the CNM algorithm, which is a more sophisticated and efficient version of the original algorithm (Clauset et al., 2004). The results for the application of community structure analysis and a discussion of the implication of the results, are presented in Section 5.2.

4.3.4. Ranking and Assessment of Policy Measures

When dealing with a large number of policy measures (options) in the formulation of policy or a policy package, one of the problems is the systematic and effective analysis of the available information. In a project such as VIBAT (Banister and Hickman, 2006b), policy-makers are fed a large number of policy measures (123 to be precise) and this entails an enormous number of possible combinations of these policy measures. The problem is further exacerbated by the existence of multiple types of relations between policy measures.

By development of a ranking and assessment methodology for policy measures, we aim to address the problem by calculating the performance of the policy measures based on user-defined criteria and using the policy measures' internal properties, interactions and other relevant available information in each specific context. The ranking and assessment methodology effectively allows quantitative comparison of the merits of alternative policy options, which can be policy measures or their combinations in the form of policy packages.

For the ranking of policy measures, we have identified three essential building blocks: (1) a library of policy measures; (2) definition and classification of the relations among the policy measures within the library; and (3) the role of the individual policy measures within the networks of relation they belong to. The concepts relating to the policy measure library and the relations among policy measure have already been introduced. In the next section, network centrality as a measure for better understanding the role that individual policy measures play within a network is introduced. Subsequently, the general methodology that can be used to combine this information for ranking and assessment of policy measures is presented.

4.3.4.1. Centrality

Centrality of a node is a measure of its importance or influence in a network. Freeman (1979) identified four types of network centralities: Degree Centrality, Betweenness Centrality, Eigenvector Centrality and Closeness Centrality. The most common centrality measure is the Degree Centrality which is used in calculating the network scores in this thesis along with Betweenness Centrality.

- **Degree Centrality**

Degree Centrality is a measure of the centrality of a node in a network based on the number of input and/or output links a node has. Degree Centrality is calculated based on the proportion of all nodes that are connected to a given node.

$$\text{Degree Centrality of a Node} = \frac{\text{Number of Incident Links}}{\text{Number of Nodes}-1} \quad \text{Eq. 4-2}$$

Furthermore, the Degree Centralization Index (DCI) is also calculated. The DCI indicates the variability of the centrality scores in a network (a more centralized network will have a larger DCI value). DCI is defined as:

$$\text{DCI} = \frac{\sum_{\text{All nodes}}(\text{Max Degree Centrality}-\text{Node's Degree Centrality})}{\text{Number of Nodes}-2} \quad \text{Eq. 4-3}$$

- **Betweenness Centrality**

Betweenness Centrality is the extent to which a node falls on geodesic paths (i.e. the shortest paths between nodes) of pairs of nodes within a network (a high Betweenness Centrality indicates that a node frequently appears on the geodesic paths). The Betweenness Centralization Index (BCI) measures the variability of the Betweenness Centralities. BCI values range from 0 to 1 (a high value indicates the existence of nodes with high Betweenness Centralities).

4.3.4.2. General Structure of the Ranking Methodology

The structure for ranking policy measures by combining the previously introduced building blocks will be described in this subsection. It is possible to develop a fixed structure based on the building blocks; however, as described in Chapter 2, it is evident that, when dealing with complex policy issues, the problem at hand is almost always context specific and a degree of flexibility to address the problem given the

geographical, temporal, political, and/or attitude of the domain experts is necessary. Therefore, a general structure for the ranking of policy measures is presented in this chapter and details of two cases of implementation are presented in Chapter 5. Figure 4-6 illustrates the proposed structure for the ranking and assessment of policy measures in a given network.

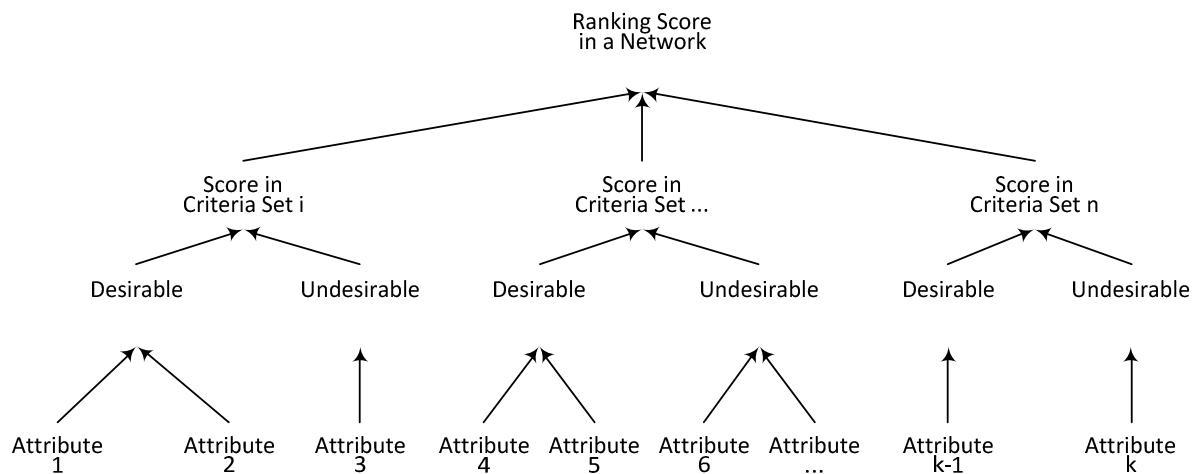


Figure 4-6 Proposed structure for the ranking and assessment of policy measures in a given network

The initial step is defining a set of attributes (e.g. effectiveness, cost, etc.) from the policy measure library. Aside from the more traditional properties described earlier, centralities (Degree In, Degree Out, Betweenness) or measures of complexity (Institutional Complexity, Public Unacceptability, etc.) can also be considered. Consideration of the attributes only takes into account the properties of that policy measure, whereas – as has been established earlier – we would also like to take into account the relations of policy measures in the networks. As an example, the calculations and significance of properties such as Total Cost and Total Time in a Precondition network can be explained as follows: (a) Total Cost – Total cost of a policy measure (the sum of costs of the measure and its preconditions). Since preconditions of a policy measure are strictly required for its successful implementation, the

real cost of the policy measure is its cost plus the cost of its preconditions. (b) Total Time – Total Time equals the sum of the time for the policy measure and its preconditions.

All the criteria in each set were assigned positive weights and were fixed to a sum of “1”. Every individual criterion within each set falls into one of the two categories ‘desirable’ and ‘undesirable’. A criterion is desirable when a high score is considered better, e.g. Effectiveness, and is undesirable when a lower score is considered better (e.g. Total Cost, Total Time). When a mix of desirable and undesirable criteria is present, by using the reciprocal of the values associated with undesirable criteria, the scores are transformed to desirable (Grunig and Kuhn (2009)). The scores obtained in both desirable and undesirable categories are then expressed as a proportion of the sum of all of the scores for each criterion. The score calculations are then based on the weighted summation of the score for each policy measure across different criteria (Eq. 4-4 and 4-5):

Calculation of the score of the policy measure with respect to the desirable criteria in a set

$$sd(k) = \sum_{j=1}^d \left(\frac{c_{kj}}{\sum_{i=1}^p c_{ij}} \times w_j \right) \quad \text{Eq. 4-4}$$

where:

- $sd(k)$: Score of the policy measure k with respect to the desirable criteria
- d : Number of desirable criteria
- p : Number of policy measures
- c_{ij} : Score of the policy measure i with respect to criterion j
- w_j : Weight assigned to criterion j

Calculation of the score of the policy measure with respect to the undesirable criteria in a set

$$su(k) = \sum_{j=1}^u \left(\frac{\frac{1}{c_{kj}}}{\sum_{i=1}^p \frac{1}{c_{ij}}} \times w_j \right) \quad \text{Eq. 4-5}$$

where:

- $su(k)$: Score of the policy measure k with respect to undesirable criteria in a set
- u : Number of undesirable criteria
- p : Number of policy measures
- $c_{i,j}$: Score of the policy measure i with respect to criterion j
- w_j : Weight assigned to criterion j

By adding up the policy measure scores across both desirable and undesirable categories, the performance score was then calculated. Hence, the policy measure with the highest score is the top-ranked policy measure in that set of criteria (Eq. 4-6):

$$\text{Score of the policy measure } k \text{ in a set} = sd(k) + su(k) \quad \text{Eq. 4-6}$$

Finally, the ranking score in a given network is defined as the weighted summation of the different criteria sets considered. Similar structures can be defined and used for comparison of policy measures in different networks in order to provide better understanding of the interactions among policy measures and a clearer picture to the experts. Effectively, this methodology converts information on qualitative relations into quantitative scores.

By considering the context and the importance domain experts give to the different networks (by assigning weights), it is possible to also calculate an overall score and

subsequently rank the policy measures. However, it must be noted that, although overall ranking of policy measures across different networks is possible, the manner in which this quantification is carried out and the logic behind it is crucial and must be defensible. The temptation to over-simplify and make unnecessary assumptions is real and often a visible shortcoming of using computational approaches when dealing with “soft” issues. The decision on what networks to consider for analysis is dependent on the opinion of the experts involved in the study and their priorities. For instance, in a study carried out by Taeihagh et al. (2011c), the information from the precondition, synergy and facilitation networks were directly used in the ranking of policy measures (see Chapter 5 for more details).

The ranking methodology: (a) combines the information about properties of a node (a policy measure) such as effectiveness, cost, time, etc. with the edges (the interactions between the nodes defined as relations in Section 4.3.1); and (b) allows for calculation of an overall score for every policy measure which can be used for ranking of the measures. As a result, the ranking and assessment methodology can provide a structured means of comparing policy measures.

4.4. Summary

In this chapter, we focused on the formulation of policy packages. An overview of the use of networks and MCDA in policy-making was provided. We provided the details of our policy measure analysis approach. Five types of interactions between policy measures were defined and the methodology used for classification and storage of these different types of relations among policy measures was presented. Finally, we highlighted how this information can be used for different visualization and analyses of the policy measures in order to gain a better understanding of their performance and complexity. The methodologies developed in this chapter can provide additional

insights into the process of policy formulation and help domain experts and policy-makers to better assess policy measures and understand the complexities involved. The methodologies can be used as a stand-alone toolkit for assessment of policy measures in the development of policy packages (Chapter 5) and/or can also be used in an ABM system for the formulation of policy packages (Chapters 6 and 7).

Chapter 5

Analysis of Policy Measures in the Formulation of Policy Packages

5.1. Introduction

Using the framework (Chapter 3) and the set of methodologies based on it (Chapter 4), systematic analyses of policy measures for the synthesis and configuration of policies have been implemented in two case studies in this chapter. The case studies focus on the formulation and analysis of policies required for achieving CO₂ emission targets in the transport sector and the promotion of walking and cycling. The goal of the development of the framework and the methodologies based on it is to accelerate the task of policy-making and improve the effectiveness of policies.

The first case study was carried out initially to explore some of our ideas using the data from the VIBAT project (Banister and Hickman, 2006b). While carrying out the study,

the results were shared with the experts at the Transport Studies Unit of the Oxford University Centre for the Environment. This resulted in a close collaboration with the Transport Studies Unit and the carrying out of the second case study on the promotion of walking and cycling for further proof of concept, as well as adoption of the approaches in the ongoing OPTIC (2010) and Visions (Tight et al. 2011) EU and UK projects.

Section 5.2 showcases the initial case study on UK transport-emission reduction and Section 5.3 provides the details of the case study applied to the promotion of walking and cycling in cities. Each case study contains an introduction to the particular problem it addresses followed by the implementation details. Results and discussion of the application of the assessment and visualization methodologies and the conclusions reached are presented for each of the case studies.

5.2. Case Study: UK Transport Emission Reduction

5.2.1. Introduction

One of the most urgent and serious challenges faced by humanity in coming years is the global warming caused by greenhouse gases (IPCC, 2007). CO₂ formed by human activity is one of the most important gases contributing to global warming. Since the industrial revolution, the levels of CO₂ emissions in the UK have risen more than 30% (Banister and Hickman, 2005). As mentioned in Section 2.1, the transport sector is the second-largest contributor to greenhouse gas emissions (IPCC, 2007), contributing around 25% of CO₂ emissions while having no contribution to emission reduction (Hickman et al., 2010).

Table 5-1 illustrates the increase of UK transport emissions in million tons of carbon (MtC) from 1985 to 2000 and the projected increase in 2015 and 2030 (Banister and Hickman, 2005). A sharp increase in the level of emissions is evident from the table. Banister and Hickman (2006a) suggest that this increase is attributed to the increased travel intensity and growth in road traffic.

Table 5-1 UK CO₂ emissions in MtC, Taeihagh et al. (2011b) based on Banister and Hickman (2005)

	1985	1990	2000	2015	2030
Road Transport	28	35	38	42	49
All Transport	31	39	41	47	52
All Emissions	156	161	149	153	166

Based on the UK government's target to reduce transport sector's CO₂ emissions by 60% by 2050 and the VIBAT project's goal of a 60% emission reduction by 2030 (Section 3.3), the importance of the design of transport policies to achieve CO₂ emission reduction is evident. Successful design of policies for dealing with such complex problems requires a systematic analysis of the information.

In this case study, an analysis of policy measures is carried out for formulating transport policies. This is done by performing:

- A Classification of the policy measure relations;
- Visualization of the networks and identification of the community structures; and
- Ranking and assessment of policy measures.

By using the framework and methodologies described in chapters 3 and 4, not only do we consider the policy measures and their internal properties, but also – by considering a network perspective – analyse and account for their complex interactions.

The 123 policy measures from the VIBAT project form the basis for these policy measure networks. Based on the interactions defined in Section 4.3.1, the relations

between policy measures were classified into five networks (Section 4.3.2). By analysing the networks and considering the internal properties of policy measures, a ranking and assessment of policy measures has been carried out and the community structures within different policy measure networks have been examined.

5.2.2. Library of Policy Measures and Their Relations

The 123 policy measures from the VIBAT project constitute the core of the library. Properties such as the policy type, effectiveness (E), Cost (C) and timeframe of implementation (T) were populated (these values are editable by the user) using explicit and implicit information provided in the Stage 3 report of VIBAT (Banister and Hickman, 2006b). For example, the ‘Standards for emissions, noise and safety’ policy measure had low cost, high effectiveness, and a medium timescale of implementation.

Subsequently, based on the interactions defined in Section 4.3, different relations between policy measures were classified as precondition (P), facilitation (F), synergy (S), potential contradiction (PC) and contradiction (C) and stored in a 123-by-123 adjacency matrix. In each network, a node represents a policy measure, which has its own internal properties, and each edge represents the relation between two nodes.

5.2.3. Application of the Ranking and Assessment Methodology

This section illustrates the implementation of the ranking methodology described in Section 4.3.4. Figure 5-1 demonstrates the structure used for the ranking and assessment of policy measures based on preconditions, and is used for illustrating the general principles. Other relationships have similar structures and all follow a similar logic.

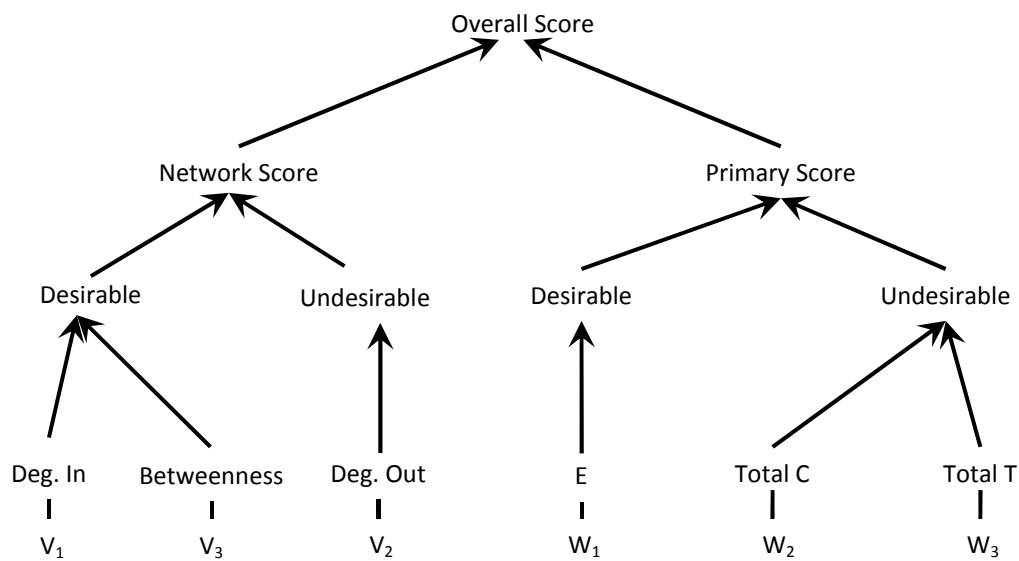


Figure 5-1 The structure of the ranking and assessment methodology based on preconditions (Taeihagh et al., 2011b)

In the first step a set of attributes, i.e. effectiveness (E), Time (T) and Cost (C) from the policy measure library were defined for the calculation of the primary score, and centralities (Degree In, Degree Out, Betweenness). As mentioned in Chapter 4, aside from consideration of the attributes of the policy measures, we would like to consider interactions within the networks. The calculations and significance of the attributes considered in Figure 5-1 are explained as follows:

- Total Cost – Total cost of a policy measure (the sum of costs of the measure and its preconditions). Since preconditions of a policy measure are strictly required for its successful implementation, the real cost of the policy measure is its cost plus the cost of its preconditions.
- Total Time – Total Time equals the sum of the implementation time for the policy measure and its preconditions³.
- Effectiveness – Effectiveness of a policy measure (a measure of its contribution to emission reduction). In the case of effectiveness, only the policy measure's effect is

³ The implementation is assumed to be done in series, which is an upper bound of the implementation time.

considered as determining the extent to which a policy measure is more or less effective due to the implementation of its precondition measures being difficult to quantify.

- Centralities – Degree and Betweenness centralities (defined in Section 4.3.4).

All of the criteria in each set were assigned positive weights and were fixed to a sum of “1”. The weight assigned to the criteria in the centrality score calculation reflects the importance of each of the attributes. For instance, a high In-Degree-Centrality of a node in the Precondition network suggests that it is a precondition to a large number of policy measures, and is considered desirable. In both sets (primary and network), a mix of desirable and undesirable criteria was present. Based on equations 4-3 to 4-5, the score calculations for each policy measure with respect to different criteria were carried out in the two sets (primary score and network score).

Finally, the overall score for a particular type of relation is defined as the weighted sum of primary and network scores. Similar structures are defined and used for comparison of policy measures in different networks in order to provide better understanding of their interactions and a clearer picture to the experts. This methodology effectively converts information on qualitative relations into quantitative scores.

5.2.4. Results and Discussion

Based on the policy measure analysis methodologies described in Chapter 4 and the implementation details presented earlier, the results and discussion of these analyses are presented in this section. First, the basic information on the networks is presented, followed by results and discussion of the policy measure ranking and assessment methodology. Finally, the results from the community structure analyses of the policy measure networks are explained.

5.2.4.1. Network Information

The summary of the policy measure networks created based on the five type of interactions defined in Section 4.3.1 is shown in Table 5-2:

Table 5-2 Summary of network information

	<i>P</i>	<i>F</i>	<i>S</i>	<i>PC</i>	<i>C</i>
No. of Nodes	123	123	123	123	123
No. of Edges	158	790	70	35	1
No. of Connected Nodes	88	123	72	25	2

Table 5-2 illustrates that Precondition, Facilitation and Synergy networks have high connection density (number of edges) and connectedness (number of connected nodes), which is expected given that the VIBAT project's aim was developing policy measures that work well together and have minimal contradictions. Table 5-2 shows that the Contradiction network is extremely limited; nonetheless, it is included in the research as the developed framework can later be used for projects in which a large number of contradictions might exist.

5.2.4.2. Results of the Ranking and Assessment Methodology

5.2.4.2.1. Network Centralities

The degree and betweenness centralities of the networks are shown in tables 5-3 and 5-4. In directed network degree centralities based on the number of edges going in or out of node are calculated and results are presented in Table 5-3. In undirected networks, the mean and standard deviations are the same for in and out degrees; however, in directed networks the standard deviations of the centralities differ. For betweenness centralities, the analyses were carried out for connected nodes in the networks only (see

Section 5.2.4.4). The Degree and Betweenness Centrality scores are used for calculating the network score of the policy measures in the next section.

Table 5-3 Summary of Degree Centrality results (Taeihagh et al., 2011b)

	<i>P</i>	<i>F</i>	<i>S</i>	<i>PC</i>	<i>C</i>
# of nodes	123	123	123	123	123
# of Links	158	790	70	35	1
Average Degree	1.285	6.423	0.569	0.285	0.008
Mean In-Degree Centrality	0.011	0.053	0.009	0.005	0
Std. Dev. In-Degree Centrality	0.018	0.035	0.011	0.011	0.001
Min In-Degree Centrality	0	0	0	0	0
Max In-Degree Centrality	0.115	0.156	0.049	0.049	0.008
Mean Out-Degree Centrality	0.011	0.053	0.009	0.005	0
Std. Dev. Out-Degree Centrality	0.014	0.064	0.011	0.011	0.001
Min Out-Degree Centrality	0	0	0	0	0
Max Out-Degree Centrality	0.066	0.426	0.049	0.049	0.008
Network DCI In	10.51%	10.39%	4.02%	4.49%	0.81%
Network DCI Out	5.55%	37.67%	4.02%	4.49%	0.81%

Table 5-4 Summary of Betweenness Centrality results (Taeihagh et al., 2011b)

Distribution of node Betweenness Centrality scores	<i>P</i>	<i>F</i>	<i>S</i>	<i>PC</i>	<i>C</i>
Mean	0	0.017	0.001	0	0
Std. Dev.	0.001	0.028	0.005	0	0
Min.	0	0	0	0	0
Max.	0.006	0.141	0.029	0.002	0
Network Node Betweenness Centralization Index	0.005%	0.125%	0.028%	0.002%	0.000%

5.2.4.2.2. From Attributes to Policy Measure Rankings

By defining the policy measure relationships (Section 4.3.1), populating the policy measure library (Section 5.2.2.), and calculating the centralities (Section 5.2.4.2.1) it is possible to perform the ranking of the policy measures following the methodology described in Section 4.3.4. Table 5-5 shows the precondition-based ranking for the first 20 policy measures:

Table 5-5 Simplified sample of the assessment of policy measures based on preconditions, policy measures 1-20

PM ID	Policy Measure	PM Basic Data			Index Based on Preconditions								
		Effectiveness	Timescale of implementation	Cost	norm-P. in	norm-P. out	norm-Betwns	Utility Value of Cost	Utility Value of Effectiveness	Utility Value of Time	Network Score	Primary Score	Combined Index
					0.4	0.4	0.2	0.4	0.4	0.2	0.2	0.8	
1	Standards for emissions, noise and safety	3	2	1	0.0443	0.0081	0.0607	0.0053	0.0118	0.0039	0.0331	0.0076	0.0127
2	Fuel quality standards	3	2	1	0.0380	0.0082	0.0000	0.0159	0.0118	0.0097	0.0185	0.0130	0.0141
3	Alternative fuel research and development	3	2	2	0.0000	0.0082	0.0000	0.0080	0.0118	0.0097	0.0033	0.0098	0.0085
4	Efficiency improvement of materials and energy (e.g. factor 4)	2	2	1	0.0000	0.0082	0.0000	0.0159	0.0079	0.0097	0.0033	0.0114	0.0098
5	Dematerialisation of products and miniaturisation	3	2	1	0.0000	0.0082	0.0000	0.0159	0.0118	0.0097	0.0033	0.0130	0.0111
6	Vehicle test cycles	1	2	1	0.0127	0.0081	0.0022	0.0080	0.0039	0.0048	0.0088	0.0057	0.0063
7	Enforcement and monitoring	2	2	1	0.0886	0.0082	0.0000	0.0159	0.0079	0.0097	0.0387	0.0114	0.0169
8	Improvement of public transport - bus, guided bus, etc.	3	2	2	0.0063	0.0081	0.0217	0.0032	0.0118	0.0039	0.0101	0.0068	0.0074
9	Increased rail capacity and high speed trains (HST)	3	3	1	0.0000	0.0081	0.0000	0.0053	0.0118	0.0039	0.0033	0.0076	0.0067
10	Public transport subsidy (investment)	3	2	2	0.0316	0.0082	0.0000	0.0080	0.0118	0.0097	0.0159	0.0098	0.0111
11	Deregulation	2	2	1	0.0000	0.0082	0.0000	0.0159	0.0079	0.0097	0.0033	0.0114	0.0098
12	Fare integration and schedule co-ordination	1	2	2	0.0000	0.0081	0.0000	0.0053	0.0039	0.0065	0.0033	0.0050	0.0046
13	Intermodality	1	2	2	0.0000	0.0081	0.0000	0.0040	0.0039	0.0039	0.0032	0.0039	0.0038
14	Traveller information	1	1	1	0.0127	0.0082	0.0000	0.0159	0.0039	0.0194	0.0083	0.0118	0.0111
15	Bus service improvement	1	1	2	0.0000	0.0081	0.0000	0.0027	0.0039	0.0039	0.0032	0.0034	0.0034
16	Park and ride	3	1	2	0.0000	0.0081	0.0000	0.0032	0.0118	0.0048	0.0032	0.0070	0.0062
17	Rail freight facilities	1	1	1	0.0000	0.0082	0.0000	0.0159	0.0039	0.0194	0.0033	0.0118	0.0101
18	Walking and cycle facilities	1	1	2	0.0316	0.0080	0.0716	0.0032	0.0039	0.0048	0.0302	0.0038	0.0091
19	Cycle/public transport integration	1	1	2	0.0000	0.0081	0.0000	0.0040	0.0039	0.0065	0.0032	0.0045	0.0042
20	Cycle parking	1	1	1	0.0316	0.0081	0.0065	0.0080	0.0039	0.0097	0.0172	0.0067	0.0088

The weight of each index defined in Section 4.3.4 is displayed below its respective column header, i.e. (a) Primary Score: Total Time 20%, Effectiveness 40%, Total Cost 40% and (b) Network Score: Degree In. 40%, Betweenness 20%, Degree Out. 40%. The combined index score is the weighted summation of Primary and Network Scores (Primary score 80% and Network score 20%).

The primary score is calculated as the weighted summation of these values using equations 4-3 to 4-5, as seen in Chapter 4. For example, for PM1 ‘Standards for emissions, noise and safety’, its Primary Score₁ = (0.4×0.0053) + (0.4×0.0118) + (0.2×0.0339) = 0.0076.

The network score of PM1 is Network Score₁ = (0.4×0.0443) + (0.4×0.0081) + (0.2×0.0607) = 0.0331

Finally, the overall score in the preconditions for PM1 is calculated in the column ‘Combined Index’: $= (0.0331 \times 0.2) + (0.0076 \times 0.8) = 0.0127$

Following similar structures, an assessment based on the other types of relations can be carried out. In this section of the thesis, the focus has been on the Precondition network, as it is the strongest type of interaction among policy measures. In Section 5.2.5 (sensitivity analysis), an alternative scenario in which the Precondition network accounts for 80% of the weight in the calculation of the overall score is considered (the remaining 16% is equally divided between Synergy and Contradiction networks and 4% equally divided between Facilitation and Potential Contradiction networks.). As will be demonstrated in Section 5.2.5, the preference and corresponding weight given to the Precondition network was strong enough to overshadow the other networks’ scores and justify focusing solely on the Precondition network. In addition, information from the networks has been successfully used both qualitatively and quantitatively in an agent-based system for the formulation of policy alternatives (Taeihagh and Banares-Alcantara, 2010, Taeihagh et al., 2011a).

5.2.4.2.3. Interpretation of the Ranking Results

In this section, we will only discuss the top-three (the highest ranked) and bottom three (the lowest ranked) policy measures (Table 5-6). Table 5-7 illustrates the complete results from the assessment and ranking of the policy measures (see Appendix A.2 for more details). To ensure the robustness and the reliability of the methodology results were carefully examined. The sensitivity analysis of different aspects of the methodologies used in the assessment and ranking of the policy measures and in the community structures analysis is carried out in Section 5.2.5.

Table 5-6 (a) the top three and (b) the bottom three policy measures in detail

<i>Top-three policy measures</i>		
	<i>Rank</i>	<i>Overall score</i>
PM7 – Enforcement and Monitoring	1	0.01690
PM31 – Integrated Planning	2	0.01491
PM2 – Fuel Quality Standards	3	0.01411
 <i>Bottom three policy measures</i>		
	<i>Rank</i>	<i>Overall score</i>
PM39 – New Urbanism	121	0.00366
PM15 – Bus Service Improvement	122	0.00337
PM113 – Cycle Priority and Road Space	123	0.00336

- **The top-three policy measures:**

The top-three highest ranked policy measures (PM7 – Enforcement and Monitoring, PM31 – Integrated Planning and PM2 – Fuel Quality Standards) are all preconditions to a large number of policy measures (PM7 is a precondition for 14 policy measures, PM31 to seven policy measures, and PM2 to six policy measures). They act as high-level policy measures, enabling and supporting the implementation of other measures. Another characteristic of the top policy measures is that they can be implemented relatively fast and have lower cost requirements while being highly effective.

- **The bottom three policy measures:**

The bottom three policy measures (PM39 – New Urbanism, PM15 – Bus service improvement, PM113 – Cycle Priority and Road Space), have the exact opposite properties in comparison to the top policy measures (none of them serve as preconditions to other policy measures but all of them have a large set of requirements for successful implementation). This results in them having a higher cost and/or implementation time requirements, while being relatively ineffective.

Table 5-7 Policy measure ranks based on the Precondition network

PM ID	Policy Measure	INDEX SUM	Rank INDEX SUM	PM ID	Policy Measure	INDEX SUM	Rank INDEX SUM
7	Enforcement and monitoring	0.016905	1	108	Traffic bundling	0.007563	62
31	Integrated planning	0.014912	2	30	Broadband, Wi-fi, smartdust and other technological development	0.007531	64
2	Fuel quality standards	0.014114	3	89	Road pricing – congestion or environmental basis	0.007446	65
88	Car and cycle parking standards for new development	0.013393	4	8	Improvement of public transport - bus, guided bus and LRT, ultra light rail, palletised	0.007438	66
32	Regional development policies, strategic planning	0.013089	5	83	Fiscal incentives for relocation in designated areas	0.007272	67
1	Standards for emissions, noise and safety	0.012717	6	22	Small wheeled public transport/paratransit	0.007272	67
68	Home delivery of goods/services	0.012627	7	53	TDM marketing	0.007272	67
103	Road capacity restraint	0.01238	8	35	Mixed use	0.007272	67
82	Pedestrian and cycle friendly developments	0.012376	9	27	Telematics, informatics available locally	0.007272	67
46	Car free planning	0.011842	10	28	Infrastructure technology	0.007272	67
118	Travel information	0.011626	11	120	Personalised travel planning, travel blending	0.007267	73
99	Airport charges	0.011367	12	104	Advanced traffic management systems	0.007161	74
21	Shuttle services	0.011367	12	115	Priorities for bus, tram and high occupancy vehicles (HOV)	0.007161	74
102	Good traffic restraint	0.011367	12	74	Carbon tax	0.007161	74
44	School travel planning	0.011367	12	77	Decentralisation of health and social services	0.007042	77
64	Guaranteed ride home	0.011367	12	78	Decentralisation of education facilities	0.007042	77
114	Direct routes for walking, cycling and PT relative to the car	0.011339	17	81	Low emission zones	0.00682	79
71	Ecological tax reform	0.011269	18	50	Eco labelling of vehicles	0.006815	80
42	Pedestrianisation	0.011184	19	9	Increased rail capacity and high speed trains (HST)	0.006748	81
14	Traveller information	0.01112	20	34	Decentralised concentration and polycentricity	0.006553	82
5	Dematerialisation of products and miniaturisation	0.011076	21	75	Taxes and feebates based on fuel consumption and weight	0.006466	83
62	Car sharing	0.011076	21	6	Vehicle test cycles	0.006331	84
67	Increased load factors	0.011076	21	92	Fuel tax/escalators	0.006319	85
85	Development restrictions and green belts	0.011076	21	25	Teleworking/telecommuting/teleconferencing	0.006248	86
10	Public transport subsidy (investment)	0.011064	25	16	Park and ride	0.006219	87
111	Road space reallocation	0.010848	26	95	Parking tariffs/pricing	0.006188	88
49	Commuter planning	0.010829	27	123	Casualty reduction targets (Zero objective)	0.006118	89
72	Tradable mobility credits	0.010559	28	106	Street reclaiming	0.006012	90
119	Transport chaining awareness	0.010323	29	105	Home zones	0.005994	91
45	Special event management	0.010323	29	55	Alternative work schedules	0.005899	92
54	Changed activity patterns - commuting, retail and/or leisure trips	0.010312	31	63	Flexitime	0.005722	93
17	Rail freight facilities	0.010107	32	56	Changing lifestyles – e.g. not travelling at weekends	0.005488	94
24	Taxi services	0.010107	32	59	Career downsizing	0.005488	94
110	Village/area bypasses	0.010107	32	93	Vehicle purchase tax	0.005483	96
112	Pedestrian priority and road space	0.009846	35	98	Excise tax for aircraft fuel	0.005483	96
91	High occupancy vehicle (HOV) pricing	0.009817	36	116	Segregated rights of way for public transport	0.005478	98
48	Car clubs	0.009817	36	97	Pay as you drive vehicle insurance	0.005472	99
4	Efficiency improvement of materials and energy (e.g. factor 4)	0.009817	36	43	Commuter trip reduction programmes	0.005379	100
11	Deregulation	0.009817	36	100	Air travel restrictions/rations	0.005306	101
61	Locally sourced retailing	0.009817	36	70	Locally sourced distribution chains	0.005219	102
96	Parking restrictions/controls	0.009572	41	58	Job location	0.005064	103
117	Increased awareness of public transport services	0.009569	42	51	Commuter financial incentives	0.005059	104
29	Multipurpose personal communications	0.009569	42	57	Home location	0.004961	105
37	Public transport orientated development (PTOD)	0.009545	44	80	Car free or low car housing	0.004955	106
109	Driver information systems	0.009329	45	38	Smart growth	0.004955	106
60	Promotion of local destinations and local activity patterns	0.0093	46	52	Parking cashouts	0.004954	108
84	Relocation of activities	0.009297	47	33	Compact cities	0.004942	109
18	Walking and cycle facilities	0.009089	48	94	Car ownership tax	0.004876	110
69	Freight distribution - centralised/decentralised centres	0.009038	49	26	Teleshopping/teleshopping/telecottages	0.004714	111
101	Entry restrictions/access control/environmental zones	0.009008	50	65	Teleworking and teleshopping	0.004701	112
41	Access to transport services	0.008823	51	12	Fare integration and schedule co-ordination	0.004642	113
20	Cycle parking	0.008799	52	90	Road tolls for freight	0.004349	114
121	Incentives to motor industry to increase hybrid car output	0.008532	53	86	Regeneration of decaying areas (city centre, inner city, waterfront, suburban)	0.004238	115
3	Alternative fuel research and development	0.008532	53	19	Cycle/public transport integration	0.004212	116
66	Logistics management	0.008532	53	23	Demand responsive services	0.004155	117
40	Clustered land use/location efficient development	0.008175	56	79	Car free district	0.003993	118
36	Zoning regulations	0.008022	57	13	Intermodality	0.003799	119
78	Carbon rations/domestic tradable quotas (DTQs)	0.008015	58	47	Campus management	0.003694	120
122	Hybrid technology research	0.008015	58	39	New urbanism	0.003663	121
76	Vehicle scrappage bonuses and tax increases	0.00801	60	15	Bus service improvement	0.003375	122
87	Housing renewal, improvements to neighbourhood quality and facilities	0.007768	61	113	Cycle priority and road space	0.00337	123
107	Traffic calming	0.007563	62				

5.2.4.3. Generation and Visualization of Policy Measure Networks

A closer look at the network of policy measures and their relations can provide useful information for the refinement of the relations and the evaluation of the policy. The average number of connections to and from a node has a large variation in some of the networks. For instance, in a Precondition network, some measures act as foundations and their implementation plays an important part in the success of other policy measures, which makes them crucial for overall policy success. However, a large number of connections can also be caused by the existence of hierarchies among policy measures (policy measure landscape not being flat and some measures being inclusive of other measures).

Analysing the nodes in terms of their input and output connections can also provide valuable information. Nodes with a large number of inputs should be implemented earlier, whereas nodes with a large number of outputs are harder to implement as they require more resources for implementation. Naturally, special attention should be paid to nodes that have a large number of both input and output connections, as they are a precondition to a large number of nodes and require a large set of preconditions themselves. Moreover, nodes with the fewest number of outputs are also important, since they are more flexible in terms of the implementation of the network.

In their initial study, Taeihagh et al. (2009a) visualized the network created from the precondition relations among policy measures using the open-source Graph Visualization Software (GraphViz) (Ellson et al., 2001), which uses the Dot plain text graph description language (Koutsofios and North, 1993). Figure 5-2 depicts the resulting network of preconditions among policy measures (in figures 5-2 and 5-3, each node (circle) represents a policy measure). The flow in Figure 5-2 is from left to right,

which means the policy measures on the right-hand side are preconditions to those in the left and thus should be implemented first.

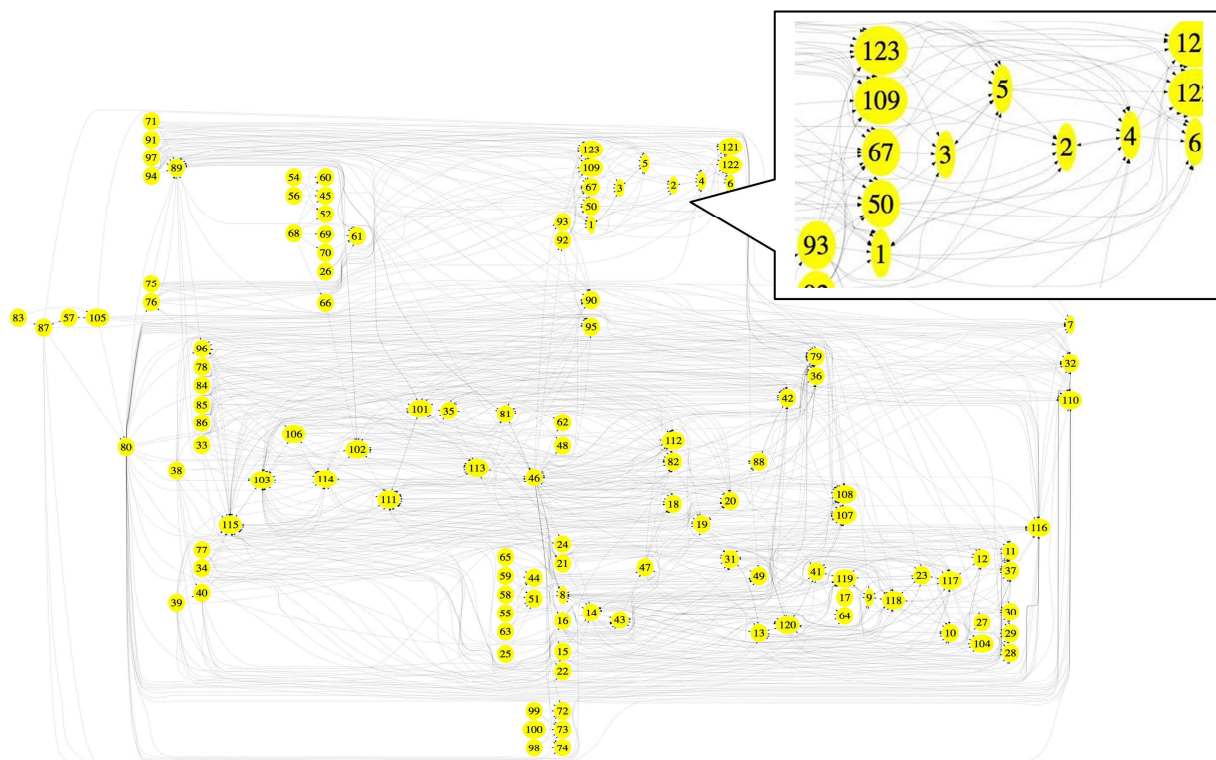


Figure 5-2 Network of preconditions with directional flow from left to right (Taeihagh et al., 2009a)

Figure 5-3 presents the same network with manually imposed clusters by Taeihagh et al. (2009a), thus creating a timeline for implementation (flow is left to right). Policy measures in the same column have the same implementation time. This type of visualization provides insights into how to order the policy measures for implementation when there are complex relations between them. However, there is an important shortcoming of the method used to produce figures 5-2 and 5-3: although each node has its own internal implementation timeframe, this has not been taken into consideration. This can have drastic effects on the desired order of implementation,

especially for the placement of measures that have a long implementation time. Furthermore, it is preferred to utilize tools and techniques to create communities of policy measures not because there are of similar type, but because of their interactions. This resulted in the use of community structure analysis, which is presented in the next section.

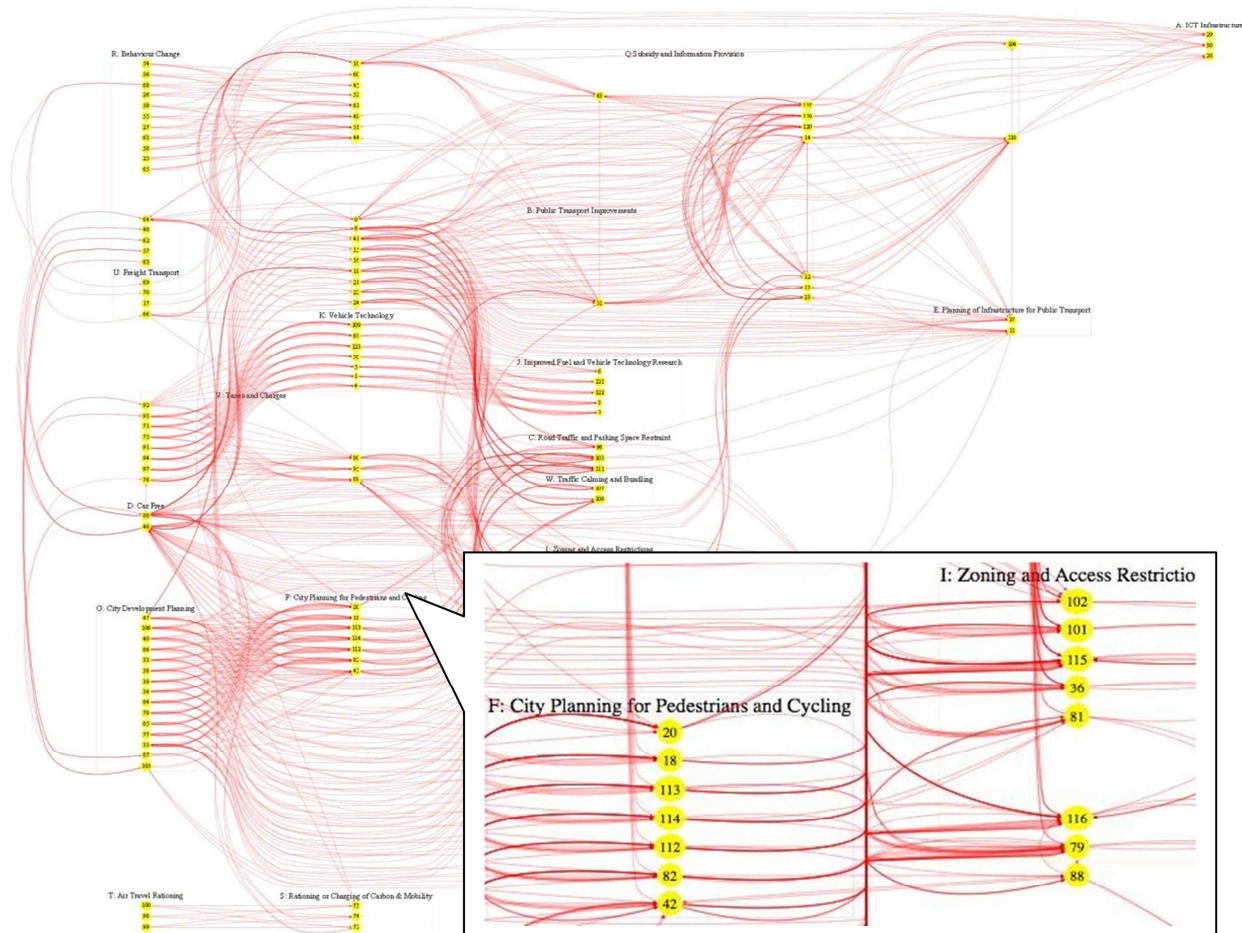


Figure 5-3 Clustered network of preconditions with a directional flow from left to right (Taeihagh et al., 2009a)

5.2.4.4. Results of Community Structure Analysis

Table 5-8 presents the summary results from application of the CNM algorithm (see Section 4.3) on the policy measure networks for identification of the community structures. The second column shows the optimal numbers of communities in each

network which occurs when the modularity (Q) reaches its maximum (Q is normally between 0.3 and 0.7). The reason for the very high level of modularity in the synergy network is that the synergy network consists of a large number of isolated components. The CNM algorithm only considers the connected nodes in the networks. The unconnected nodes are excluded from the analysis (the optimal modularity is indifferent to inclusion of the unconnected nodes). In the case of directed networks, directed edges were ignored, and the networks were treated as undirected.

Table 5-8 Summary of community structure results (Taeihagh et al., 2011b)

Network	Number of Communities	Maximum Modularity
<i>P</i>	7	0.656
<i>F</i>	4	0.362
<i>S</i>	16	0.848
<i>PC</i>	4	0.527
<i>C</i>	1	0.0

5.2.4.4.1. Assessing the Adequacy and Implications of the Community Structures

The community structuring approach provided by the CNM algorithm was tested for its adequacy as a tool for supporting the domain experts in policy packaging. A detailed analysis of the policy measures was carried out to check whether the policy packages obtained by the use of computational methods make physical sense. Given the different nature of the networks of interactions among policy measures, it was important to understand which network benefited the most from identification of community structures and how this information could be used for understanding the complex interactions and hidden structures of the policy measures used in formulating policies.

The synergy network shows the positive reinforcing effect of policy measures on each other. The synergy network, as explained earlier, contains many isolated components; Figure 5-4 depicts a part of the synergy network, which contains a large number of nodes. Visualization of the network provides a picture of the positive reinforcing

interactions; however, application of the CNM algorithm allows us to better identify the structures formed by the policy measures.

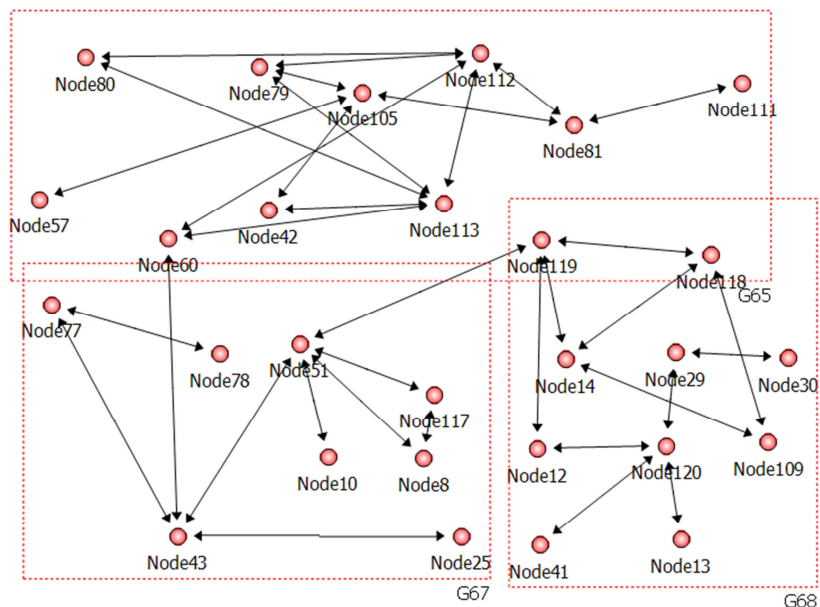


Figure 5-4 Visualization of three clusters created by the CNM algorithm over the synergy network

Figure 5-5 is the list of the policy measures in each of the three clusters identified by the CNM algorithm in the synergy network depicted in Figure 5-4 (the manually created VIBAT policy packages are shown for comparison). A close look at the clusters makes it evident that there are often strong connections between different synergistic sets of policy measures that form clusters of measures. In the case of Figure 5-5a, the ten measures are from policy packages five, six and eight in the selected community. These policy measures all relate to community planning issues and the allocation of road spaces. In Figure 5-5b, all of the measures relate to decentralization and the promotion of public transport. Figure 5-5c revolves around information technology and the enabling of personalized travel plans for travellers. Similar to the aforementioned clusters, all other clusters have themes such as air travel, parking and vehicle pricing, rail freight, vehicle taxation and incentives, etc.

(a)	Cluster G65
	<u>VIBAT PP5</u>
	42 Pedestrianization
	113 Cycle priority and road space
	112 Pedestrian priority and road space
	<u>VIBAT PP6</u>
	57 Home location
	80 Car-free or low-car housing
	81 Low-emission zones
	105 Home zones
	111 Road space reallocation
	79 Car-free district
	<u>VIBAT PP8</u>
	60 Promotion of local destinations and local activity patterns
(b)	Cluster G67
	<u>VIBAT PP6</u>
	77 Decentralization of health and social services
	78 Decentralization of education facilities
	<u>VIBAT PP4</u>
	10 Public transport subsidy (investment)
	8 Improvement of public transport - bus, guided bus and LRT, ultra-light rail, etc.
	<u>VIBAT PP7</u>
	25 Teleworking/telecommuting/teleconferencing
	43 Commute trip-reduction programmes
	<u>VIBAT PP3</u>
	51 Commuter financial incentives
	<u>VIBAT PP8</u>
	117 Increased awareness of public transport services
(c)	Cluster G68
	<u>VIBAT PP8</u>
	119 Transport chaining awareness
	118 Travel information
	12 Fare integration and schedule co-ordination
	120 Personalized travel planning, travel blending
	<u>VIBAT PP7</u>
	14 Traveller information
	109 Driver information systems
	29 Multipurpose personal communicators
	30 Broadband, Wi-Fi, smartdust and other technological developments
	<u>VIBAT PP6</u>
	13 Intermodality
	41 Access to transport services

Figure 5-5 Details of the policy measures in the community structures presented in Figure 5-4 (Taeihagh et al., 2011b)

The Girvan and Newman algorithm was designed for the analysis of sparse networks and is not suited for densely connected networks such as the facilitation network (Girvan and Newman, 2002). In the case of the facilitation network, the algorithm

yields four clusters with a very large number of nodes, which is not well suited for direct use in the selection of policy measures.

The Precondition network illustrates the dependence of policy measures on each other for successful implementation. Application of the CNM algorithm on the Precondition network results in the identification of communities of policy measures that are closely dependent on each other. The clusters facilitate the identification of self-containing units of policy measures that can be implemented successfully with minimum reliance on policy measures from outside of a cluster. It must be noted that, given the complex nature of interactions among policy measures, it is predictable that not all of the requirements of the policy measures are within a single cluster. However, the aim would be to identify groups of policy measures within communities that maximally satisfy each other's implementation requirements. Figure 5-6 illustrates one such cluster, where the selection of policy measures from within the cluster satisfies the majority of the requirements of the measures. Arrows pointing out of the central box indicate policy measures which have requirements from outside the central cluster.

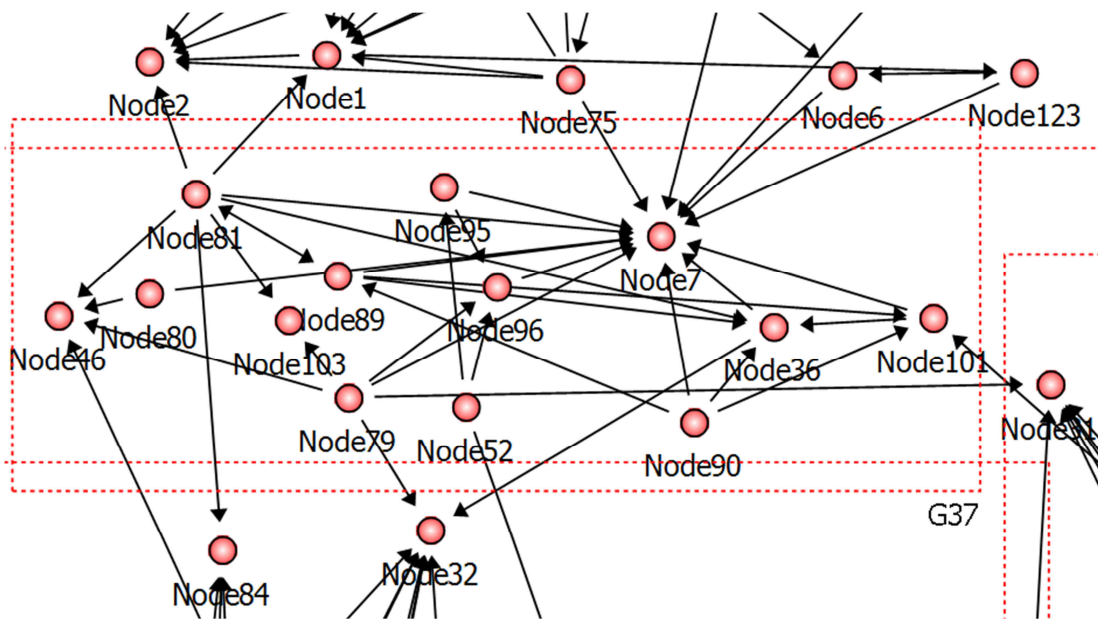


Figure 5-6 A sample cluster from the Precondition network

Identification of policy measures that sit on the boundaries of the clusters is important, as they – unlike the core policy measures of a cluster – are more likely to have diverse requirements and a higher likelihood of requiring policy measures from outside of the cluster for their successful implementation. Visualization of the networks and identification of the communities makes understanding the requirements of the policy measures easier. This can result in better decisions while considering whether and/or how to consider the boundary policy measures in a package. Any decision made should also consider the interactions that have not been satisfied within a package and minimize the negative effects in case dependencies exist. In Figure 5-6, it is apparent that if nodes 7, 36, 46 and 96 are selected for implementation in a package they would support the successful implementation of many of the other policy measures. Nodes such as node 90, however, do not directly benefit any other nodes in the cluster and can be easily removed from any potential package without negative effects. In contrast, border nodes such as 7 or 81 can have a direct impact on many nodes within and outside the cluster. In such cases, their removal from the package can result in severe problems in the implementation of other policy measures within the package. However, in the case of node 81, its removal has a minimal impact on policy measures outside of the cluster and only affects one node internally. In contrast, nodes such as 89 or 96 are located in the core of the cluster and do not affect any of the nodes outside it.

Figure 5-7 illustrates the application of the CNM algorithm on the largest component of the Potential Contradiction network, which has split it to two clusters. This clustering can help in identifying policy measures that can have maximal potential incompatibilities with each other, as well as helping to avoid such nodes being placed within a package. It might be inevitable to have two policy measures that can be potentially contradictory within a package but, by applying the CNM algorithm, it is possible to identify the more complex negative interactions and avoid them.

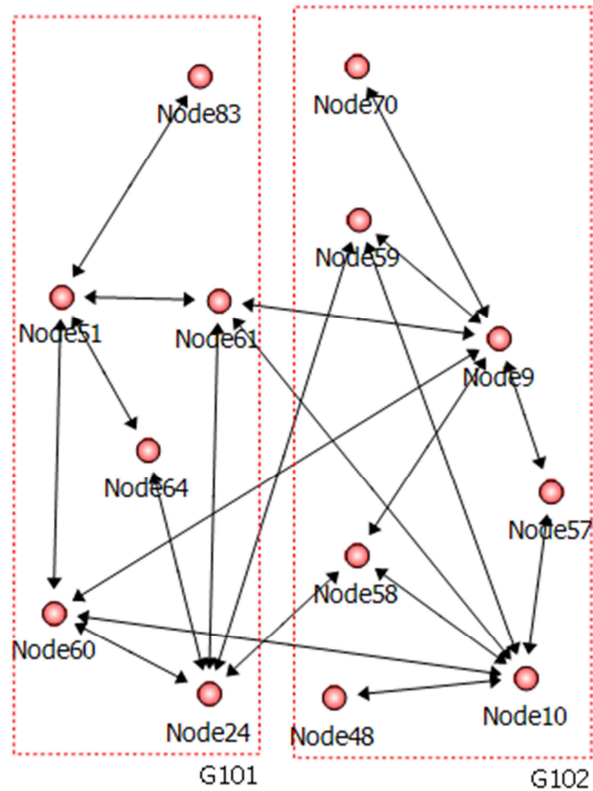


Figure 5-7 A sample cluster from the potential contradiction network

From examination of the different networks, it is evident that “not all networks are equal” when it comes to the application of the community structure analysis. These differences can stem from the nature of the network or can be context specific and due to the nature of the policy measures under analysis. It should be stressed that we are by no means suggesting that these results are an acceptable alternative to expert opinion during the manual formulation of policy packages.

5.2.4.4.2. Analysis of the Patterns of Policy Measure Communities in Different Networks

An observation resulting from the analysis of the community structures in different networks was that certain policy measures were always together in the same community. The significance of this phenomenon is the identification of the strong structural dependency that a policy measure has on other policy measures. This

phenomenon also occurs when two policy measures do not have a direct tie with each other but keep appearing together in the same clusters in different networks. Analysis was carried out on the Precondition, Synergy and Facilitation networks. In order to identify these patterns, the communities that each policy measure belonged to in different networks were identified. The intersections of these communities were found and policy measures that always remained in the same community as the policy measure under analysis were identified. The analysis was taken one step further by identifying the intersections of the resulting pattern obtained from the previous step for individual policy measures. For instance, when considering policy measure 76 (Vehicle scrappage bonuses and tax increases) in the community structures of the Precondition, Synergy and Facilitation networks, it was identified that policy measures 71, 75, 92, 93, 94 are always in the same structure. However, policy measure 76 has no direct links with policy measures 93 (Vehicle purchase tax) or 94 (Car ownership tax). Such observations can help policy experts identify those policy measures with the strongest interactions and the nature of these dependencies/interactions, which might not always be apparent when visualizing the networks.

5.2.5. Sensitivity Analysis

5.2.5.1. Sensitivity Analysis of the Ranking Methodology to Input Relations

There are 123 nodes present across the five networks with 1054 links between them. It is important to consider the fact that there may be some errors in defining such a large number of interactions. In order to understand the effect of such errors on the overall system, a sensitivity analysis was carried out on the input data matrix in the form of a Monte Carlo simulation (MCS) with 10,000 iterations. Assuming a 3% error rate in defining the relations, in each iteration 32 connections were manipulated randomly, and the results from the rankings were compared with the original data. In each iteration, 32 sets consisting of two integers from 1 to 123 and one real number between 0 and 1 were

generated. The first two random integers identified the location of the cell in the matrix containing all of the relations. In cases where the matrix cell was already occupied with a relation, it was removed and, when the cell was empty, a relation type was defined using the third number in the sets (a random real number between 0 and 1). The space between 0 and 1 was divided into five sections representing five types of relations in segments that were proportional to their relative number. For instance, the precondition relation constitutes 0.1499% of the overall links (158/1054). If the random real number generated was between 0 and 0.1499 and the cell was empty, a precondition relation was defined in that cell.

After manipulation of the overall matrix, results were compared with the original results from the analysis. Figure 5-8 and Table 5-9 depict the frequency in which policy measures have a change of ranking of more than 10 and 20 positions. They also summarize the sensitivity analysis on the policy measure ranking results, when matrix manipulation is carried out in the MCS. The hardware used for the sensitivity analysis consisted of an Intel Core i7 640m CPU and 8Gb RAM. The MCS was performed in approximately seven hours for the 10,000 iterations (see Appendix A.1 for MCS code).

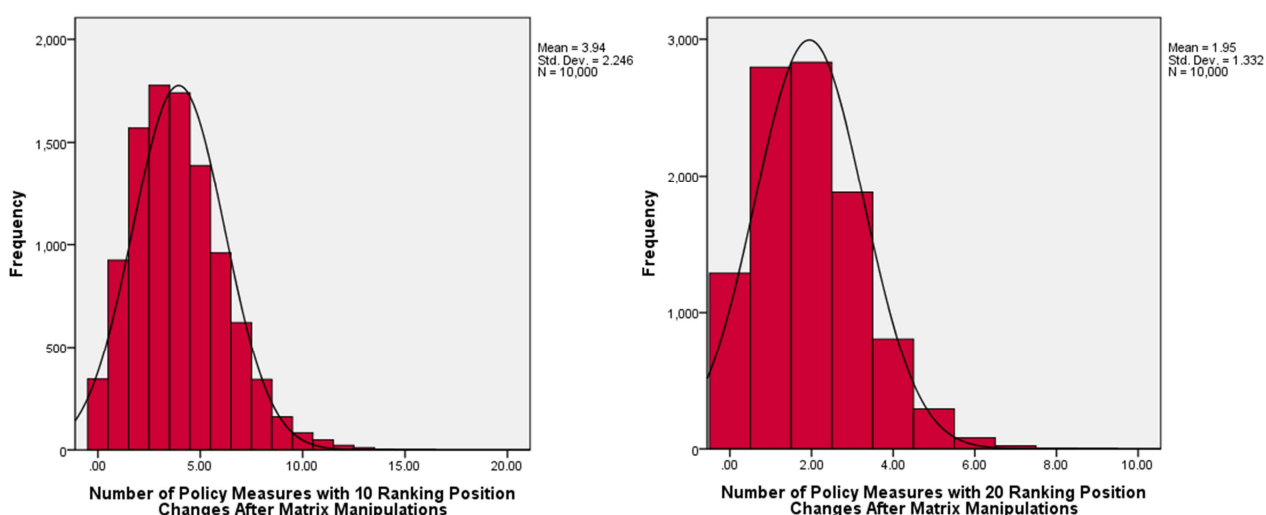


Figure 5-8 Frequency of change of policy measure ranking: (Left) More than 10 positions; (Right) More than 20 positions

Table 5-9 Sensitivity of the policy measures to input data

Ranking Position Changed After Matrix Manipulations	Mean	% of the Overall Policy Measures (For Mean)	Median	Standard Deviation	95% Confidence Range
>10	3.94	3.2	4	2.246	0-8
>20	1.95	1.58	2	1.332	0-4

The results from the MCS show the robustness of the ranking system to a relatively large number of random errors in the input data (32 manipulated relations). As indicated in Table 5-9, on average less than four policy measures had a change in ranking of more than 10 positions and less than two policy measures had a change of ranking of more than 20 positions out of the 123 policy measures in 10,000 iterations.

In our experience of working with experts in the development of relational datasets, the occurrence of a 3% error rate is unlikely. It is more likely that the experts miss some of the relations rather than defining them incorrectly, which makes the 3% error assumption in this section an upper bound limit. Furthermore, smaller sets of MCS of 1000 iterations each with a variety of different error rates were performed, which further illustrates the robustness of the ranking methodology at 4 and 5% error rates as seen in Table 5-10. Overall, the sensitivity analysis shows that the resilience towards random input data manipulation is very high and that the ranking results are robust.

Table 5-10 Number of ranking position changes based on different error rates

% Error Introduced	2	3	4	5	7.5	10	15	20
Mean	1.3990	1.9370	2.5410	3.1020	4.6220	6.2260	8.7840	11.7670
Median	1.0000	2.0000	2.0000	3.0000	4.0000	6.0000	9.0000	12.0000
Std. Deviation	1.12475	1.31330	1.52665	1.64569	1.96646	2.32343	2.67778	3.31356
0.95 Confidence Range	0-3	0-4	0-5	0-6	0-8	0-10	0-14	0-18

5.2.5.2. Sensitivity to the Change of Weights of the Internal Criteria

A 10% change of weight to the criteria used for the calculation of both primary and network scores was applied. In every instance where weights were changed, the rest of the weights were adjusted proportionally. Figure 5-9 shows the shift in ranking positions of the policy measures under six scenarios, with different weights for the three criteria used in primary score calculations (weights were changed by $\pm 10\%$). In none of the six scenarios was there a significant change in the ranking of the policy measures. Increases in the effectiveness weight has the most significant effect on the ranking; however, even in this case only two out of the 123 policy measures (1.6%) had a change of ranking greater than 20 positions (16%).

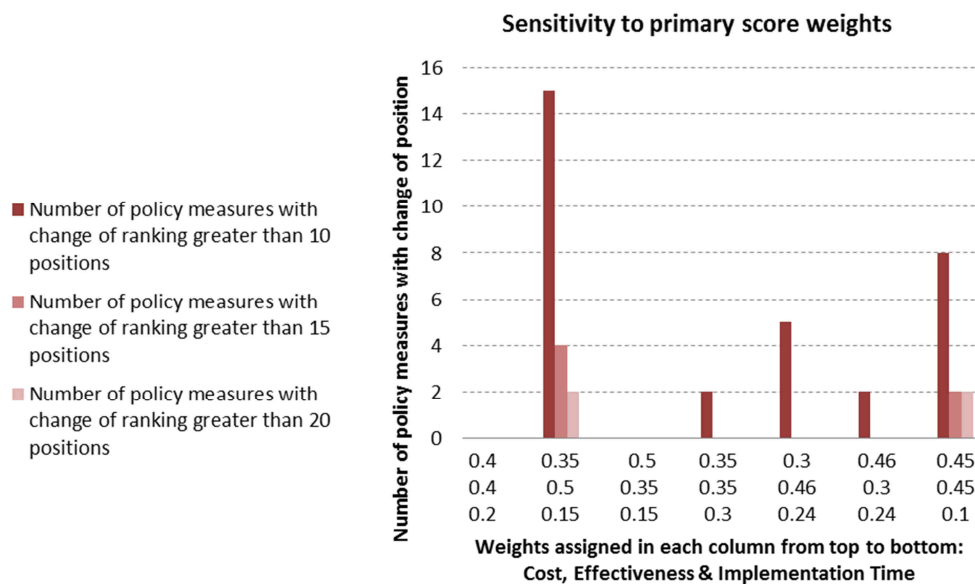


Figure 5-9 Sensitivity of the primary score weights. Number of changes to policy measures position in the overall ranking out of 122 maximum possible changes of rank.

Figure 5-10 illustrates the shift in the ranking positions under six scenarios, varying the weights of the three criteria used for network score calculations by $\pm 10\%$. Similar to the previous test, none of the six scenarios caused a significant change to the ranking of the policy measures. At most, three of the policy measures out of the 123 (2.4%) have a change in ranking greater than 20 positions (16%).

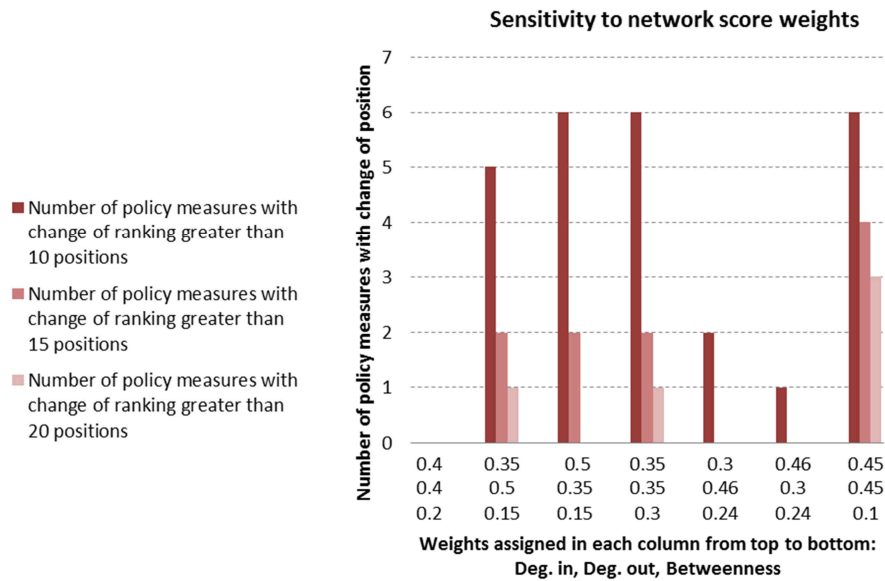


Figure 5-10 Sensitivity to network score weights. Number of changes to policy measures position in the overall ranking out of 122 maximum possible changes of rank.

Figure 5-11 depicts the effect of changing the weights associated with network and primary scores used for ranking of policy measures. The effects of a $\pm 10\%$ change in weights were considered. As anticipated, the effect of changing the weights associated with the network and primary scores on the overall ranking of the policy measures was stronger than for the change of weights associated with individual criteria. Overall, less than eight policy measures out of 123 (6.5%) had a change of ranking of greater than 20 positions (16%).

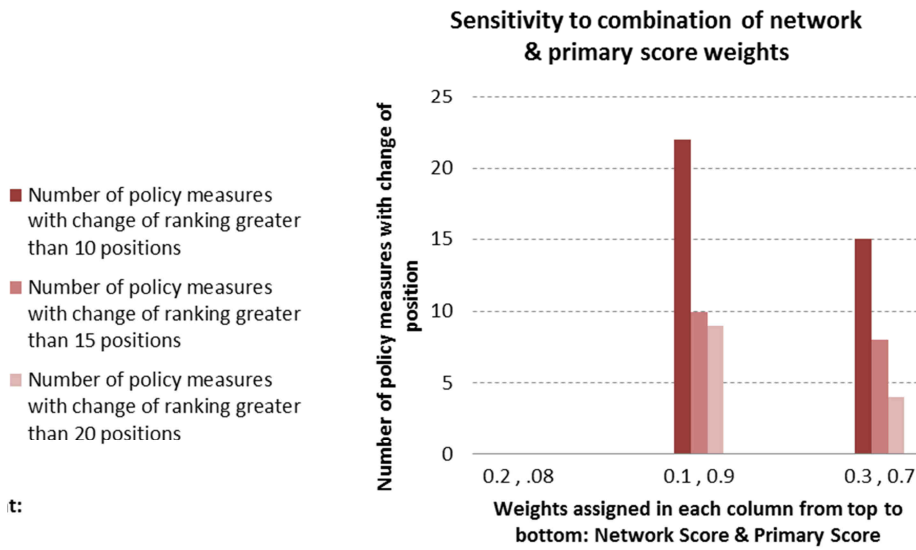


Figure 5-11 Sensitivity to change in weights assigned to network and primary scores for the calculation of the overall scores. Number of changes to policy measures position in the overall ranking out of 122 maximum possible changes of rank

Analysis of the different scenarios therefore shows a high level of resilience to reasonable levels of variation in the weighting of criteria.

5.2.5.3. Sensitivity to the Weights Assigned to Different Networks

As mentioned earlier, the focus in this case study has been on the Precondition network, as it is the strongest type of interaction among policy measures. An alternative scenario in which the Precondition network accounts for 80% of the weight in the calculation of the overall score and an intermediate scenario in which preconditions account for 90% of the score were also considered. In the scenario where 80% of the weight is assigned to the Precondition network, 16% of the total weight was equally divided between the Synergy (8%) and Contradiction networks (8%), and 4% between the Facilitation (2%) and Potential Contradiction (2%) networks. In the intermediate scenario, the distribution was 90% (precondition), 4% (synergy), 4% (contradiction), 1% (facilitation), and 1% (potential contradiction).

Figure 5-12 depicts the effect of considering other networks aside from the Precondition network in the ranking of policy measures. Naturally, the effect of considering multiple networks is more pronounced than the effects seen in the previous sensitivity analyses. However, in the intermediate case only one policy measure had a change in ranking of more than 20 positions (16%). In the more extreme case, 12 policy measures (9.7%) had a change of ranking of more than 20 positions (16%). The high level of resilience of the ranking mechanism (more than 90% not having any significant change in ranking) confirms the decision to focus exclusively on the Precondition network.

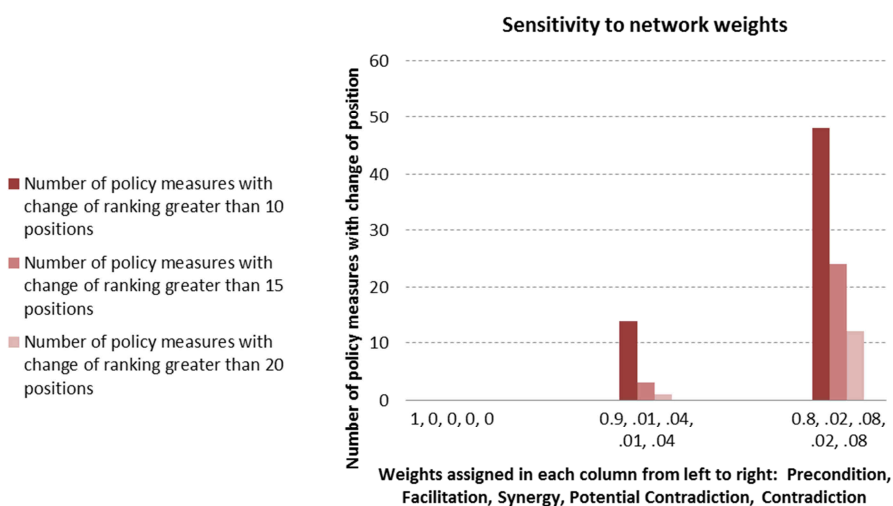


Figure 5-12 Sensitivity to change of compositions of networks considered for ranking of the policy measures. Number of changes to policy measures position in the overall ranking out of 122 maximum possible changes of rank

5.2.5.4. Sensitivity of the Community Structure Analysis to the Input Data Errors

While analysing the robustness of community structures, Karrer et al. (2008) state that, for real networks “we can say that about 20% of the edges must be rewired before 20% of the vertices move to different communities”. In line with this observation, the effect of 3% random input errors in the specification of policy measure relations (described in

Section 4.3.1) on the community structures formed across the Precondition, Facilitation, Synergy and Contradiction networks was insignificant.

5.2.6. Conclusion

The purpose of this case study was to explore and examine a number of network analysis techniques in the context of policy formulation. We have worked on a case study to reduce the UK transport emissions. In contrast to traditional approaches to policy design, we have concentrated on the interactions between policy measures, inspired by concepts from process design and network analysis.

Using the policy measure library extracted from the VIBAT project, we explored five types of policy measure relationships: precondition, facilitation, synergy, potential contradiction and contradiction. By definition and classification of these relations, five networks of policy measure relations were created, each with the 123 nodes (policy measures) and their interactions as the edges. Different analyses were performed on these networks of policy measures. A policy measure ranking and an assessment methodology was developed to improve quantitative comparison of the policy measures. The methodology systematically combines the policy measure properties (effectiveness, cost and implementation time), policy measure relations and the relative importance of a measure in the network measured by centralities, through application of a weighting mechanism defined by the user. Moreover, network visualizations and community structure analysis using the CNM algorithm was carried out in order to help experts to better understand the interaction among policy measures. Finally, an extensive set of sensitivity analyses was performed to ensure the validity of the results.

Significant effort has been invested in the design and implementation of the policy measure assessment and ranking methodology; however, further enhancements in the

structuring of the system can be made. We acknowledge that policy measures may have other attributes that have not been considered and further enhancements to include a more complete set of criteria are possible. Furthermore, the policy measures used in the analysis are not flat and include hierarchies. This has already been identified as a limitation in the VIBAT project and has been addressed by testing the methodology in the second case study on the promotion of walking and cycling in close collaboration with transport policy experts.

The potential areas for future work have been identified and are presented in Chapter 8. The methodological framework is generic and can be applied to other domains (energy, water, etc.). We believe that the assessment and ranking methodology could be applied successfully in other projects and we present the second case study in Section 5.3. The results from this case study make a fresh contribution to formulation of policies by:

1. Developing a new approach to the analysis and ranking of policy measures that captures the relationships among them alongside their internal properties;
2. Providing a quantitative framework for comparison of policy measures based on user-defined criteria; and
3. Exploring the community structures to help experts gain deeper understanding of the relations among policy measures in different networks.

5.3. Case Study: Promotion of Walking and Cycling in Cities

5.3.1. Introduction

Transportation, or mobility, is an integral part of our society. Transportation is a driving force in economic growth and our lifestyles, and is a catalyst for globalization. However, transportation is also a major cause of climate change and air pollution.

Transportation systems are often subject to public policy due to their importance and effect on our socio-technical systems and their provision is not left to the markets.

Banister (2008) defines the current approach to try to improve the cost/benefit balance of our societies' transportation needs as sustainable mobility (sustainable transport). In many countries, the focus is on increasing the levels of walking and cycling (see Boarnet 2006, Tight and Givoni 2010, Pucher and Buehler 2008 and Rietveld and Daniel 2004). The main policy objective in cities and countries is to encourage active travel (i.e. use of non-motorized transport).

Walking and cycling have been in decline and there is a substantial potential for an increase. Cycling declined from 23 to 5 billion passenger kilometres (DfT, 2007) between 1952 and 2006 in Britain, despite the large increase in population, especially in cities. However, 66% of trips are under five miles and 19% under one mile, which are distances suitable for walking and cycling (DfT, 2009). A few countries that have seen a decrease in the use of walking and cycling have been able to reverse the trend successfully, therefore providing evidence of successful policies to promote walking and cycling (Pucher and Buehler, 2008).

The "Visions of the role of walking and cycling in 2030" research (Tight et al., 2011) examines the development and evaluation of three alternative visions for the year 2030 in which walking and cycling play a more significant role in urban transportation in comparison to the current state. Tight et al. (2011) identified almost 150 individual policy measures to promote walking and cycling. A combination of these policy measures is required in order to change the current state in which walking and cycling represented just 26% of trips in urban areas in 2010 to a future state in which walking and cycling represent about 70% of trips in urban areas by 2030 (see Tight et al., 2011 for more details).

Well-designed and thought-through policy packages are needed to achieve the visions developed by Tight et al. (2011). With about 150 policy measures and various possible combinations of them as choices for action, however, policy-makers cannot be expected to be able to systematically consider them all. To support and facilitate policy-makers in carrying out such considerations, the methodology proposed in Chapter 4 is applied to the question of improving rates of walking and cycling.

5.3.2. Application of the Ranking and Assessment Methodology

In order to apply the methodology described in Chapter 4, the following inputs are required: a library of policy measures, the internal properties of each policy measure, and the type of relation between each pair of policy measures in the library. To test the methodology and simplify its application and illustration, 38 measures – from the 142 originally identified by Tight et al. (2011) – were selected for analysis in order to carry out a more detailed study than in first case study and to avoid some of the limitations of the initial case. The measures were selected to represent different types of policy measure (infrastructure, regulation, education, etc.), all likely to affect the propensity to walk and cycle in different ways (through pull and push factors, changes in cycling and walking conditions, changing attitudes, effecting the use of other modes, etc.).⁴ The list of 38 measures is described in Section 5.3.3 (see Table 5-12).

Eight attributes for each policy measure were considered, representing two dimensions of a policy measure's characteristics, one with respect to its *performance* and the other with respect to its *implementation complexity* (Taeihagh et al., 2011c). The latter is considered the cost of overcoming issues such as political and institutional barriers

⁴ The selection process focused on ensuring that different types of measure were included, and was performed by experts at the Transport Studies Unit at the University of Oxford.

represented as the “transaction costs” related to implementing a measure⁵. Splitting the criteria into two sets, and assuming mutual independence among criteria within each set, effectively allowed two separate assessments of the policy measures. Following Dodgson et al. (2001) completeness, operationality, mutual independence and other relevant factors were considered in the definition of the criteria.

The five ‘performance’ attributes considered were:

- Cost (C): cost of the implementation of the policy measure.
- Effectiveness (E): effectiveness of the measure in affecting the policy target.
- Timescale of implementation (TI): time required to implement the measure.
- Delay (D): length of time from the implementation of the policy measure to the time its effects are felt.
- Timescale of Effect (TE): length of time during which the measure’s effect will be felt after implementation.

Three additional properties are used for assessing the ‘implementation complexity’ of the policy measures. These three additional properties were used by de Bruin et al. (2009) to rank different measures to address climate-change policy. In the context of policy packaging, these three properties are essential, even if difficult to measure:

- Technical Complexity (TC): degree of technical challenges in the implementation of the measure.
- Public Unacceptability (PU): degree of likely public opposition to the implementation of the measure.

⁵ Milgrom and Roberts (1990) define transaction costs as ‘the costs of deciding, planning, arranging and negotiating the action to be taken and the terms of exchange when two or more parties do business; the costs of changing plans, renegotiating terms and resolving disputes as changing circumstances require; and the costs of ensuring that parties perform as agreed’.

- Institutional Complexity (IC): degree of tension with existing practices and structures when implementing the measure. In other words, the barriers to implementation stemming from current procedures within the relevant bureaucratic organizations and the mismatch between desire, authority and jurisdiction to implement a measure.

All eight criteria/properties were qualitatively assessed by the analyst using a low, low/medium, medium, medium/high and high scale (see Appendix A.3 for more detail). Later, these qualitative assessments were translated into scores ranging from 1 (low) to 5 (high). For example, a policy measure such as ‘Private motor vehicle ownership restrictions’ was established to have a relatively low cost, high effectiveness, low implementation time, long-lasting effect, medium time period required for the effect to be felt from the time of implementation, high technical and institutional complexity and high level of public unacceptability in comparison to other policy measures under consideration. These values correspond to scores of 1, 5, 1, 5, 3, 5, 5 and 5, respectively.

Next, identification of the relations between each pair of measures was required, to determine if no relation exists or which of the five relations defined in Section 4.3.1 exists, followed by inputting this into the relational matrix (Section 4.3.2). This process forces the experts to explicitly analyse and consider each policy measure and how it interacts with other policy measures. Eventually, a 38-by-38 adjacency matrix representing all of the interactions between the policy measures present in the library was produced⁶ (see Appendix A.4).

For the assessment and ranking of policy measures, we focus on the precondition relations and use facilitation and synergy relations in a limited fashion. The

⁶ An Excel spreadsheet was used to enter the relation between each pair of measures

precondition relations aggregate the nodal information of each criterion; for example, the total cost equals the sum of the Cost (C) of the policy measure and its preconditions. Other calculations and aggregations are made in the same manner following a Traditional MCDA approach but also accounting for the precondition measures. In all of the score calculations, the following two rules apply: (a) preconditions of a policy measure are strictly required for its successful implementation; and (b) it cannot be generically prescribed that all of the preconditions can be implemented concurrently (in parallel). Therefore, in the various calculations related to timescales (described below) the total time required for implementation is the sum of the implementation time of a policy measure and those of its preconditions (i.e. the implementation is assumed to be done in series, which is an upper bound of the implementation time).

In order to compare and highlight the effect of the policy measure relations on the ranking result, two approaches were used for analysis: the Traditional MCDA and the Network-Centric MCDA. In both cases, ranking was based on the weighted summation of the score for each policy measure. Weights used for the criteria in each set were identical in both approaches⁷. In the Traditional MCDA case, policy measures were ranked according to their scores based on their intrinsic properties and assuming independence between the policy measures. However, in the network-centric approach interactions with other policy measures were taken into account alongside the intrinsic properties of the nodes; therefore, the policy measures' scores were also dependent upon the types and numbers of interactions they had.

The following calculations were performed to derive the score for a measure in the Network-Centric MCDA approach. Total Implementation Time equals the sum of the

⁷ Assignment of weights to the criteria was based on the judgement of experts at the Transport Studies Unit of the University of Oxford. The weights used were as follows: Performance ranking: Total Implementation Time 20%, Total Effect 40%, Cost 40%. Complexity ranking: Technical Complexity 20%, Public Unacceptability 40%, Institutional Complexity 40%.

Timescale of Implementation (TI) and the Delay (D) for the policy measure and its preconditions. Total Effect equals Timescale of Effect (TE) of the policy measure multiplied by the policy measure's Effectiveness (E), in this case without considering the effect of the preconditions, since determining the extent to which a policy measure is more or less effective due to the implementation of its precondition measures is difficult to quantify. For Public Unacceptability and Technical and Institutional Complexities, the value associated with the policy measure is the sum of the scores it has for the individual measure and all of its preconditions.

Figure 5-13 demonstrates the structure used for calculating performance and complexity scores. As explained in Section 4.3.4 and applied in the first case study in Section 5.2.3, all of the criteria in each set were assigned positive weights and fixed to a sum of "1". In the first set (performance criteria), a mix of desirable and undesirable criteria was present. The scores obtained in both the desirable and undesirable categories were then expressed as a proportion of the sum of all of the scores for each criterion and multiplied by the weight assigned to that criterion (equations 4-3 and 4-4). By adding up the policy measure scores across both desirable and undesirable categories, the performance score was then calculated. Hence, the policy measure with the highest score in the first set was ranked as the top policy measure in terms of performance (Eq. 4-6).

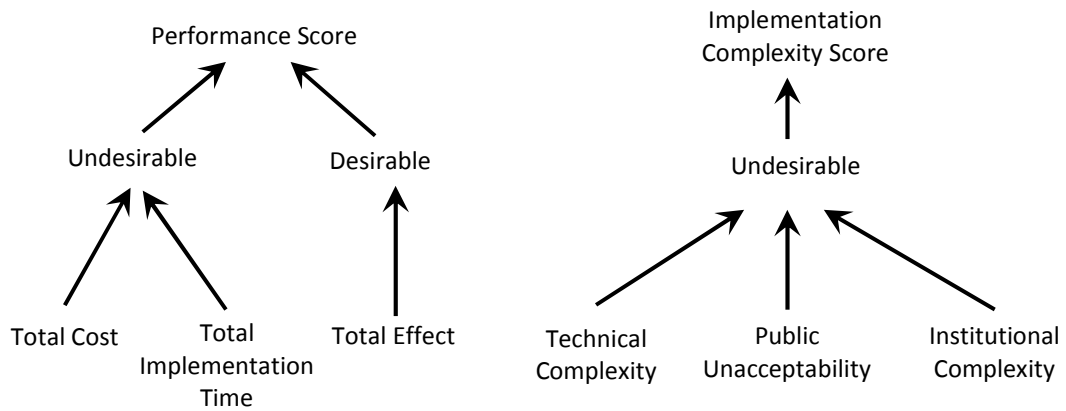


Figure 5-13 Structure of the performance and implementation complexity scores

As all of the criteria in the second set (implementation complexity criteria) were undesirable, there was no need to convert the undesirable criteria to desirable. Therefore, the policy measures scores were simply summed up and the policy measure with the lowest score was the top ranked, i.e. the one with the least transaction costs (Eq. 5-1).

Calculation of the implementation complexity score (second set of criteria)

$$\text{Implementation complexity score of the policy measure } k = \sum_{j=1}^m \left(\frac{c_{k,j}}{\sum_{i=1}^p c_{i,j}} \times w_j \right)$$

Eq. 5-1

where:

m : Number of criteria

$c_{i,j}$: Score of the policy measure i with respect to criterion j

p : Number of policy measures

w_j : Weight assigned to criterion j

In the network-centric approach, facilitation and synergy relations were used to discriminate between policy measures in cases where there was a tie in the overall score (rank). For instance, everything else being equal, a measure that has facilitation or synergy relations with other measures is preferred to one that does not have this type of relations. It must be noted that it is difficult to estimate the magnitude of these positive effects *a priori* and thus it is not possible to compare policy measures quantitatively in terms of the number of facilitation or synergies they have and conclude which one is more advantageous.

5.3.3. Results and Discussion

The results of the analysis of the 38 measures to increase walking and cycling are presented below. First, the network analysis is presented and discussed, followed by the results for the ranking of measures.

5.3.3.1. Analysis and Visualizations of the Policy Measure Networks

Using common network analysis indices (e.g. density, average degree and connectedness – Krackhardt, 1994), the overall network characteristics of the library of measures can be described. This, however, is of little importance since there is no intention to implement or select all of the policy measures in the library. What are of importance and interest are the individual network characteristics of each measure. Below, each network is visualized separately and independently from the others using the Fruchterman and Reingold (1991) algorithm, which places the most connected nodes in the centre of the network.

The Contradiction network consists of only two measures, “on-road cycle-path” (measure ID: 54) and “Dutch-style segregated cycle paths” (57). While it is clear that implementing both is not possible in the same place, it might be appropriate to use each in different parts of a proposed cycle network. The network visualizations are more helpful in showing different aspects of the networks when the networks of relations are more complex. Figure 5-14 visualizes the Potential Contradiction network. It provides visual information on policy measure combinations that should be avoided or should be carefully considered before implementation. The central node in the Potential Contradiction network is the “On-road cycle paths” (54) node. It has four potential contradictory relations with other policy measures in the library, which might be a reason to opt for segregated cycle paths. Whether to opt for on-road or off-road cycle paths is generally undecided and there is a rich body of literature available on the subject matter (Pucher and Dijkstra, 2000; Forester, 2001). Therefore, in order to make a decision, local circumstances would have to be considered.

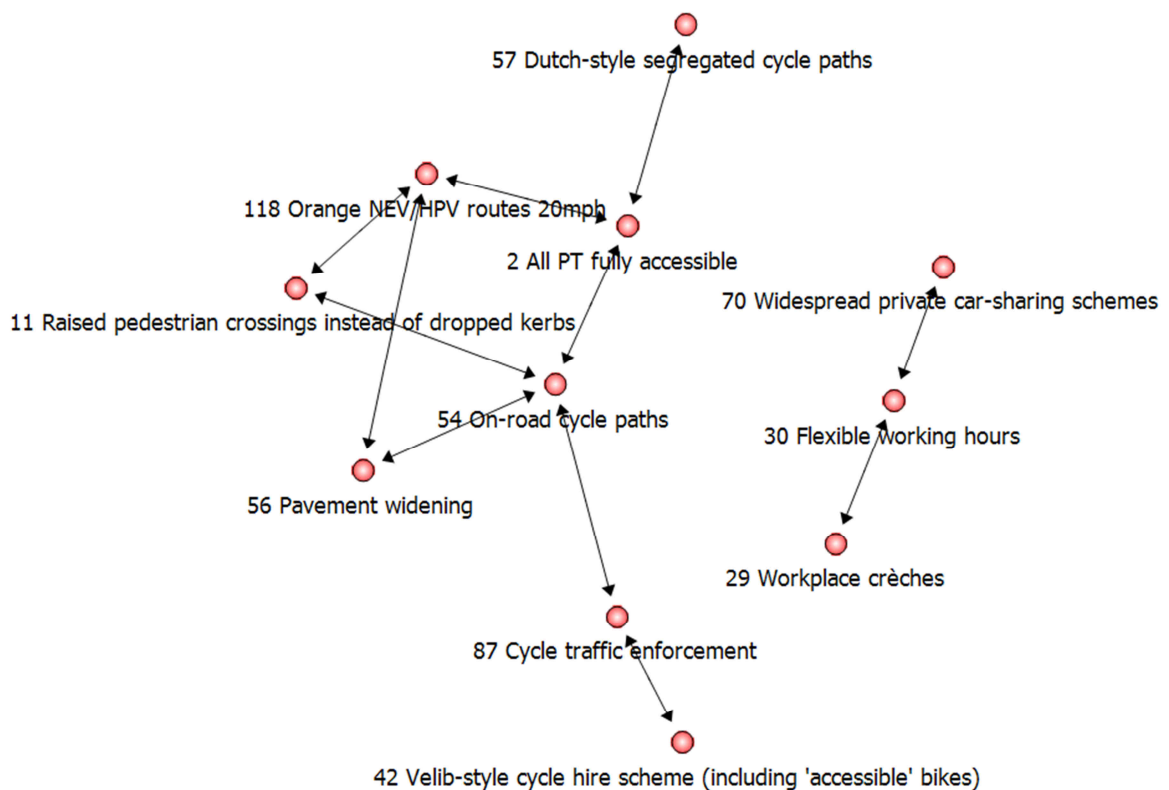


Figure 5-14 Visualization of the Potential Contradiction network

Figure 5-15 visualizes the Precondition network, which is more complex. It is difficult to envisage that policy-makers would be able to infer similar information in regard to the complex precondition relations of the policy measures and their implications without performing the pairwise analysis of the policy measures and the visualization of the resulting networks.

By analysing the network information in this case study, it is evident that successful implementation of “car-free housing development” (112) is only possible if policy measures 2, 3, 61 and 70 have been successfully implemented. Of course, some of these policy measures have preconditions of their own. For instance, “mandatory core walking and cycling networks” (61) has “mandatory ringfencing of walking and cycling funds” (34) as a precondition and these complexities should be recognized when planning to use a measure like a “car-free housing development” (112).

Furthermore, Figure 5-15 highlights policy measures that enable successful implementation of a large number of other measures. For example, if “Pavement widening” (56) is implemented, this enables the consideration of many other measures (7, 10, 13, 21, 57, 61). Therefore, it might be beneficial to include such a policy measure in a policy package to increase walking and cycling regardless of whether such a policy measure is perceived to have low values in different criteria. “Pavement widening” (56) has a high appeal as, aside from its own merits, it serves as a precondition for “Mandatory ‘core’ walking and cycling networks” (61), which in turn is a precondition for “Private motor vehicle ownership restrictions” (103). Without the use of visualizations, the centrality of a policy measure such as “Pavement widening” (56) can be overlooked when considering a large number of policy measures in a library. Moreover, using visualizations can help in better communicating the need for such a policy measure. One interesting observation is that almost all of the policy

measures forming the Precondition network are related to infrastructure, implying the perceived importance of such policy measures.

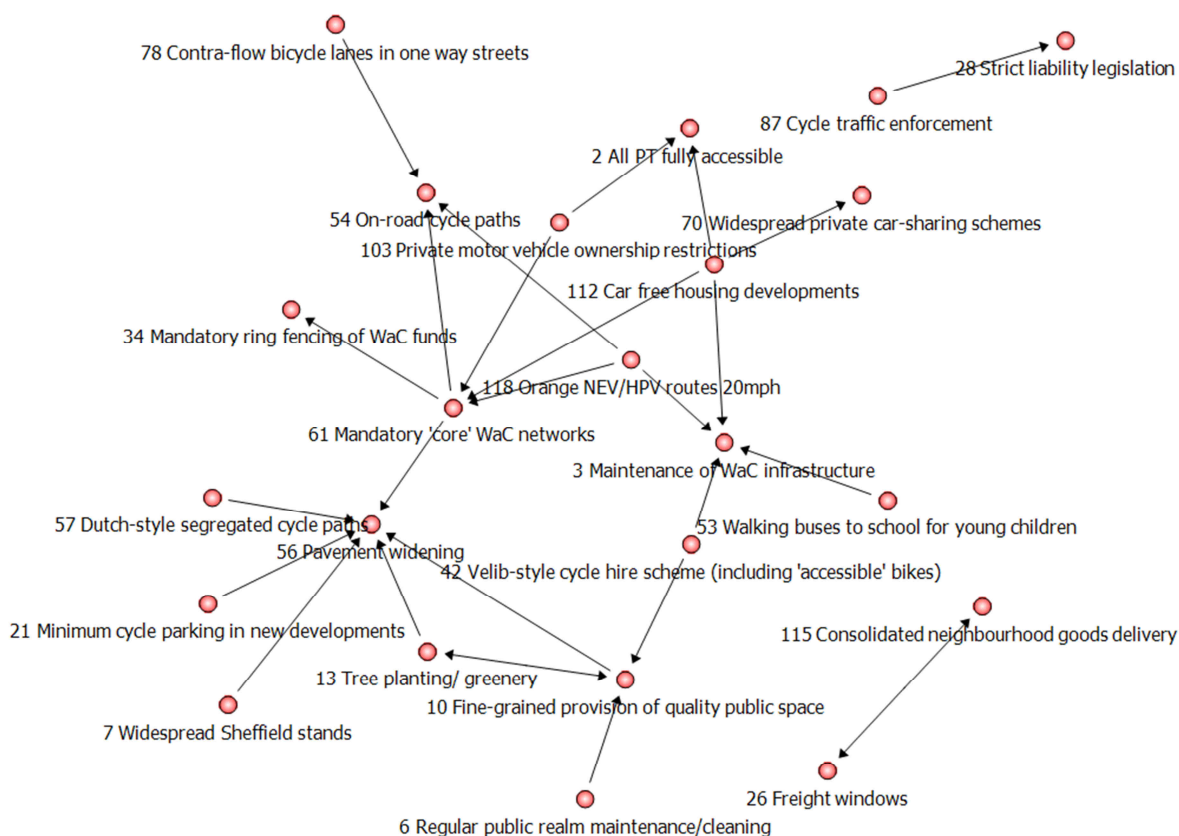


Figure 5-15 Visualization of the Precondition network

Through analysis of the facilitation and synergy networks, focus is shifted from the implementation aspects to the effectiveness of the policy measures to promote walking and cycling. The level of complexity of the facilitation network is such that it is more difficult to examine the visualizations; nonetheless, important information can be inferred. Similar to the Precondition network, policy measures that facilitate the effectiveness of many other measures (in-degree) and policy measures that are facilitated by many other measures (out-degree) require special attention. To assist our understanding the facilitation network, Table 5-11 provides the number of edges going

out and into each policy measure in the network. Furthermore, the facilitation network has been visualized in two separate figures (figures 5-16 and 5-17), where nodes are scaled based on the number of links connected to them (degree).

Table 5-11 Representation of the walking and cycling Facilitation network

Policy Measure (ID from the original study)	Out-degree	In-degree
All public transport fully accessible (2)	4	0
Maintenance of walking and cycling (WaC) infrastructure (3)	1	5
Regular public realm maintenance/cleaning (6)	1	5
Widespread Sheffield stands (7)	1	3
Opt-out travel training for all school children (8)	0	1
Fine-grained provision of quality public space (10)	2	4
Raised pedestrian crossings instead of dropped kerbs (11)	0	4
Tree planting/ greenery (13)	0	1
Minimum cycle parking in new developments (21)	0	2
Freight windows (26)	0	1
Strict liability legislation (28)	0	2
Workplace crèches (29)	1	0
Green belt (31)	7	0
Smart 'oyster-style' cards for all mobility (33)	0	3
Mandatory ringfencing of WaC funds (34)	0	9
All city parking for private car to be pay and display or permit (36)	0	2
Removal of 'rat runs' for motorized vehicles (38)	0	2
Velib-style cycle hire scheme (42)	14	0
Dutch-style railway parking facilities (47)	3	3
Community leisure walks and bicycle rides (52)	12	0
Walking buses to school for young children (53)	10	1
On-road cycle paths (54)	3	3
Pavement widening (56)	3	4
Dutch-style segregated cycle paths (57)	4	2
Mandatory 'core' WaC networks (61)	3	9
Widespread private car-sharing schemes (70)	1	1
City-wide 20mph speed limit (72)	1	7
Limits on car advertising (75)	2	5
Contra-flow bicycle lanes in one-way streets (78)	3	3
Public fitness campaign (79)	4	2
Smart bicycle storage units (86)	2	0
Cycle traffic enforcement (87)	1	1

Retrofitting cul-de-sacs for WaC connectivity (94)	1	8
Private motor vehicle ownership restrictions (103)	5	1
Car-free housing developments (112)	10	3
Orange NEV/HPV routes 20mph (118)	2	4

Note: Out-degree represents the number of policy measures that facilitate the individual measure. In-degree represents the number of policy measures that the individual measure facilitates.

Policy measures that facilitate a large number of other policy measures (i.e. have a high in-degree value in Table 5-11 and a large number of arrows pointing towards them in Figure 5-16) are more interesting to policy-makers. In Figure 5-16, “Mandatory core walking and cycling networks” (61) and “Mandatory ringfencing of walking and cycling funds” (34) are examples that facilitate nine other policy measures each. It is therefore important to try to include these policy measures in a package, after considering policy measures’ internal characteristics (such as cost, perceived effectiveness, etc.) in contributing to walking and cycling. By checking out the Precondition network, it becomes apparent that policy measure 34 is a precondition to 61. This suggests that it is desirable to include both of these policy measures in a package and, if only one can be included in a package due to constraints, it must be policy measure 34.

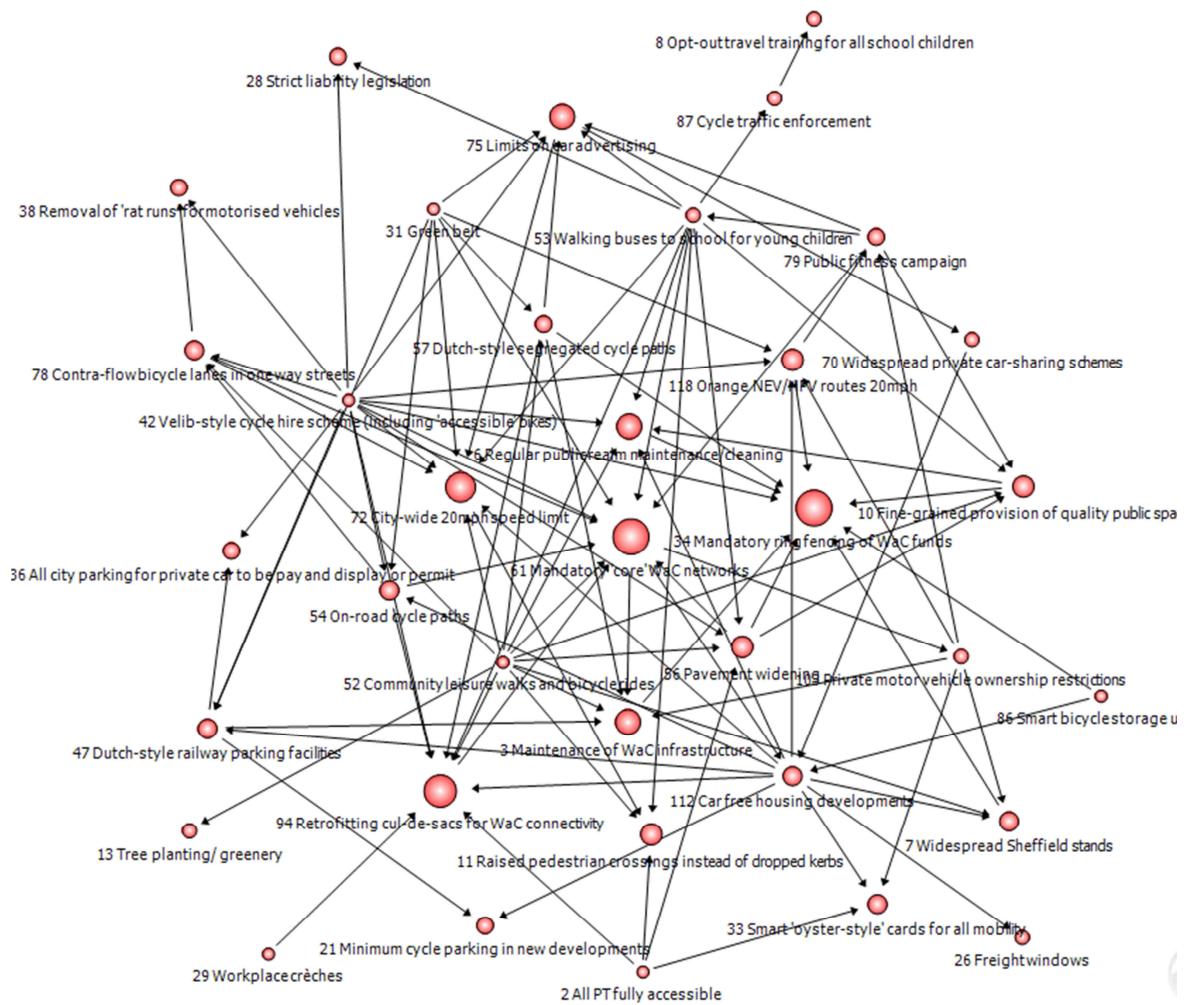


Figure 5-16 Visualization of the Facilitation network based on in-degree values (nodes are scaled based on the number of links connected to them)

The out-degree column in Table 5-11 and Figure 5-17, on the other hand, illustrates the extent to which a certain policy measure’s effectiveness can be enhanced by the implementation of other policy measures in the facilitation network. As described in Section 4.3.1, it is worth emphasising that a facilitation relation is not defined as a restriction, although it might be perceived as a soft restriction. “Velib-style cycle hire scheme” (42) can be facilitated by 14 other policy measures and stands out as a measure that can be made much more effective with the support of other policy measures. Bicycle hire schemes have become widespread and following their introduction on the streets of Paris (although not the first of such schemes), London introduced its own scheme in 2010. While “Velib-style cycle hire scheme” (42) is a policy measure that

directly addresses the goal of promoting cycling, it is evident that its success can be facilitated by a wide range of other policy measures (but is not necessarily dependent on them). It might be possible for some of the relations defined here to be changed to precondition relations as more experience and understanding is gained on this particular type of a policy intervention. The facilitation network also implies that policy measures such as “Community leisure walks and bicycle rides” (52) and “Walking buses to schools for young children” (53), which are relatively ‘simple’ and cheap, might have a real impact when other policy measures have been implemented. The importance of considering a policy measure’s relations with other measures alongside its internal properties is therefore apparent.

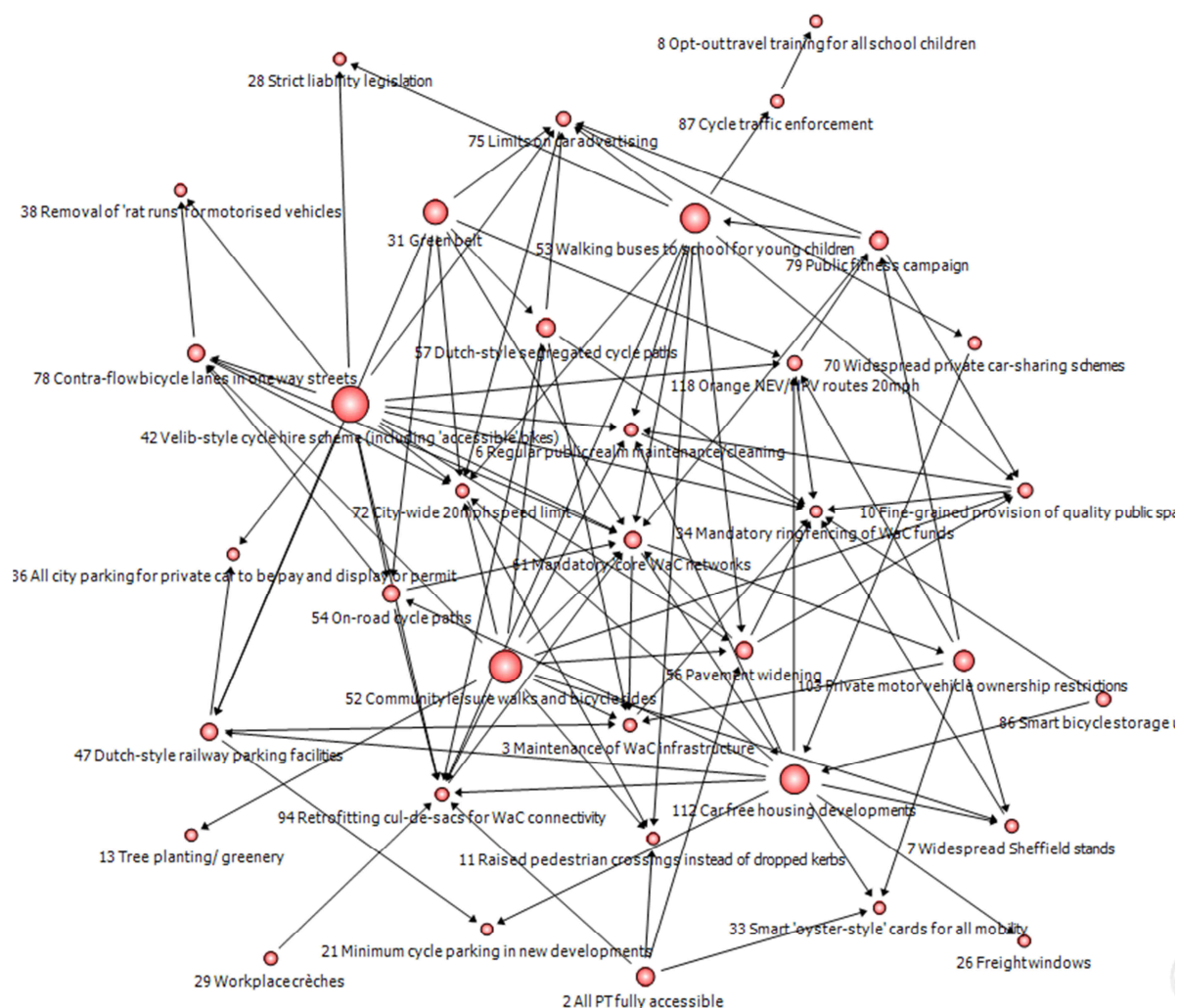


Figure 5-17 Visualization of the Facilitation network based on out-degree values (nodes are scaled based on the number of links connected to them)

The last visualization shows the network of synergy relations (Figure 5-18), where nodes are scaled based on the number of links connected to them (degree). From Figure 5-18, “Private motor vehicle ownership restrictions” (103) immediately stands out as a policy measure that has synergy with a large number of other policy measures (12 synergy relations), implying it is a very important policy measure to include in a package to increase walking and cycling. Of course, policy measure 103 does not directly address walking and cycling, which highlights the significance of considering a combination of policy measures, including some with indirect effects on the policy goals. Such a policy measure might not appear to be important in terms of the

formulation of walking and cycling policy without the use of visualization. It must be noted that these visualizations do not provide any information about the internal characteristics of the policy measures. For instance, “Private motor vehicle ownership restrictions” (103) is likely to be very difficult (publicly and therefore politically) to implement, something not apparent from the visualizations. It is possible to use colour, size variations or different shapes for policy measures to represent some of the properties; however, it would be very challenging to adequately represent all of the properties in the same figure. Furthermore, this increase in the complexity of the networks has its own drawbacks and can even cause confusion in cases where both internal and relation information are presented in the same figure. Therefore, obtaining information about the internal properties of policy measures through data gathered for the assessment and ranking of measures is easier.

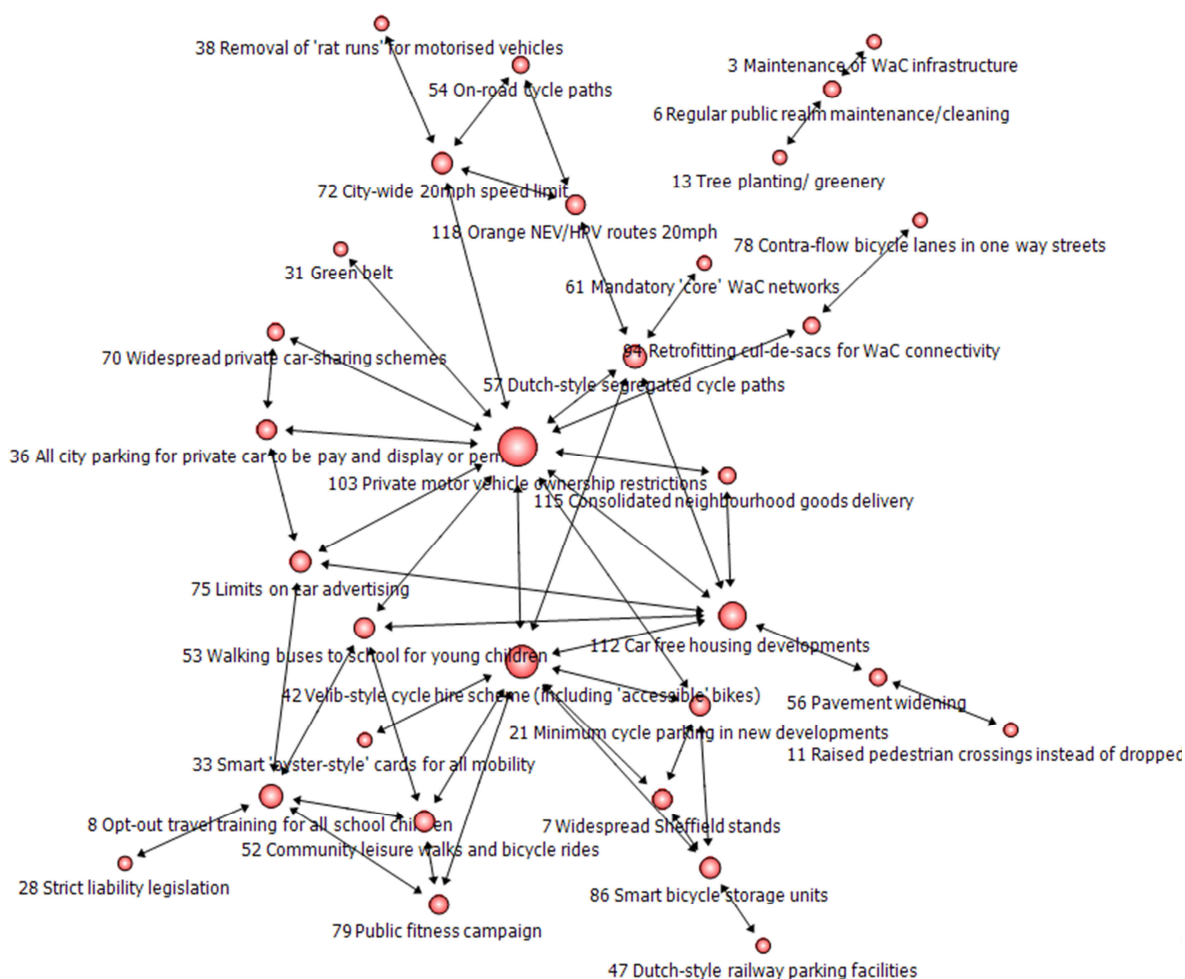


Figure 5-18 Visualization of the Synergy network (nodes scaled based on their degree)

As demonstrated in this subsection, visualizations of the policy measure networks offer vital additional information that can be used while considering their ranking and selecting which policy measure to implement. The crucial step of bringing together the knowledge gained through the analysis of the different networks and relating it to the performance and implementation criteria, as well as the results yielded by the ranking of policy measures, is left to the judgement of the experts.

5.3.3.2. Results for Ranking of the Policy Measures

Using the methodology described in Chapter 4, two rankings have been generated (Table 5-12): a *performance-based ranking* where measures are ranked based on their cost, effectiveness and time-related properties, and an *implementation-based ranking*, where the ranking reflects the technical and institutional complexity of the measures as well as their public (un)acceptability (see Appendices A.5-A.8 for more detail). The philosophy of MCDA suggests that weights can be put on the performance and implementation rankings to produce one index, but this was avoided in order to prevent the dilution of the information that would result from merging the two different dimensions. We propose instead considering the performance of various measures before paying attention to the barriers for their implementation, since implementation barriers can often be overcome with supportive (additional) measures. For each of the two ranking sets, two further sets are presented based on (a) a Traditional MCDA ranking and (b) a network-based MCDA ranking, where the precondition relations are accounted for⁸.

⁸ The scores for each measure, which determine the ranking, are not shown.

Table 5-12 Ranking of measures to promote walking and cycling based on their 'performance' and 'implementation' attributes using Traditional MCDA and Network-Centric MCDA

MEASURE TITLE	Performance		Implementation	
	Traditional	Network	Traditional	Network
All public transport fully accessible (2)	28	20	1	1
Maintenance of WaC infrastructure (3)	24	15	1	1
Regular public realm maintenance/cleaning (6)	30	37	1	23
Widespread Sheffield stands (7)	23	30	1	21
Opt-out travel training for all school children (8)	37	31	19	10
Fine-grained provision of quality public space (10)	26	35	29	33
Raised pedestrian crossings instead of dropped kerbs (11)	31	26	19	10
Tree planting/ greenery (13)	31	38	10	33
Minimum cycle parking in new developments (21)	2	14	9	23
Freight windows (26)	9	33	34	30
Strict liability legislation (28)	8	5	34	25
Workplace crèches (29)	31	26	30	19
Flexible working hours (30)	31	26	34	25
Green belt (31)	7	3	37	27
Smart 'oyster-style' cards for all mobility (33)	31	26	25	15
Mandatory ringfencing of WaC funds (34)	5	2	10	6
All city parking for private car to be pay and display or permit (36)	15	6	10	6
Removal of 'rat runs' for motorized vehicles (38)	9	4	10	6
Velib-style cycle hire scheme (including 'accessible' bikes) (42)	17	18	8	28
Dutch-style railway parking facilities (47)	25	21	19	10
Community leisure walks and bicycle rides (52)	19	8	1	1
Walking buses to school for young children (53)	11	25	10	18
On-road cycle paths (54)	12	7	10	6
Pavement widening (56)	16	12	28	17
Dutch-style segregated cycle paths (57)	17	16	33	30
Mandatory 'core' WaC networks (61)	20	19	25	37
Widespread private car-sharing schemes (70)	38	32	1	1
City-wide 20mph speed limit (72)	4	1	19	10
Limits on car advertising (75)	21	9	25	15
Contra-flow bicycle lanes in one-way streets (78)	1	11	10	22
Public fitness campaign (79)	36	24	1	1
Smart bicycle storage units (86)	22	13	19	10
Cycle traffic enforcement (87)	13	23	10	29
Retrofitting cul-de-sacs for WaC connectivity (94)	14	10	31	20
Private motor vehicle ownership restrictions (103)	2	17	37	36
Car-free housing developments (112)	5	22	10	33
Consolidated neighbourhood goods delivery (115)	28	33	19	30
Orange NEV/HPV routes 20mph (118)	26	36	31	37

Note: When the difference in ranking between the Traditional MCDA and the Network-Centric MCDA is more than 10 places, the network-centric rank is emphasised (bold numbers).

Based on their intrinsic performance attributes (the Traditional MCDA), the three top ranking measures are: “Contra-flow bicycle lanes in one-way street” (78), “Minimum cycle parking in new developments” (21), and “Private motor vehicle ownership restrictions” (103). When accounting for the fact that these measures all have precondition measures (see Figure 5-17), their rankings in the Network-Centric MCDA change to 11th, 14th and 17th respectively. Assuming the precondition relations have been correctly identified, not accounting for them would result in a misguided choice of policy measures. For example, the measures “Limits on car advertising” (75) and “Public fitness campaign” (79) are ranked 12 places higher in the network-centric than in the traditional ranking because they have no preconditions attached to them. Whenever preconditions are present, they must be implemented to allow successful implementation of their supporting policy measure. This increases the costs and, given the high weight assigned to Cost in this analysis (C - 40%), the existence of a precondition is seen as undesirable. The ranking of the measure “Freight windows” (26) (i.e. restricting the delivery of freight into the city to certain hours only), on the other hand, has dropped 24 places. Because of its preconditions, this policy measure has moved from being a relatively attractive measure (ranked 9th using Traditional MCDA) to being one of the least attractive in terms of its performance (ranked 33rd using Network-Centric MCDA). The performance attributes of the policy measure and its precondition therefore make policy measure 26 unattractive. This information could not have been directly inferred from the visualizations.

Based on the Network-Centric MCDA ranking, the three most effective measures in the library are: “City-wide 20mph speed limit” (72), “Mandatory ringfencing of walking and cycling funds” (34) and “Green belt” (31 – the restriction of city development to within a “belt” surrounding it). When two measures share the same ranking (i.e. they

received the same score), they can be further discriminated by also considering the facilitation and synergy relations they have with other measures.

The “implementation complexity” ranking provides information on potential barriers to the implementation of various policy measures (technical, public unacceptability and institutional barriers – Section 5.3.2). Seven of the policy measures with the least implementation barriers are ranked jointly first (measures 2, 3, 6, 7, 52, 70 and 79). Five of these seven policy measures remain as top-ranked policy measures based on the network-centric ranking, as they do not have any preconditions attached to them. When considering their precondition measures, the policy measures “Regular public realm maintenance/cleaning” (6) and “Widespread Sheffield stands” (7 – provision of metal bars placed in the road/pavement for bicycle parking) drop to the 23rd and 21st ranking positions. The policy measures that have relatively few implementation barriers, not surprisingly, have a relatively poor performance ranking, with the exception of “Community leisure walk and bicycle rides” (52), which is ranked 8th in the performance ranking using the Network-Centric MCDA method.

The policy measures “Removal of ‘rat runs’ for motorized vehicles” (38 – designation of small streets as one-way streets in order to avoid drivers using them as short cuts) and “Mandatory ringfencing of walking and cycling funds” (34) both have a high performance ranking (2nd and 4th) and both rank 6th in the implementation complexity ranking, making them relatively attractive to implement first. Policy measure 34 is also central in the facilitation network (Table 5-11). The policy measure “City-wide 20mph speed limit” (72) is considered highly effective and is ranked first in terms of performance. Furthermore, it has no particular implementation barriers (ranked 10th, which means medium/high public unacceptability but low institutional and technical complexity) and appears as an attractive policy measure to include in a package for promotion of walking and cycling.

In contrast, policy measures such as “Green belt” (31) and “Strict liability legislation” (28) which rank highly in terms of their performance (3rd and 5th respectively) appear to be very problematic in implementation, ranking 27th and 25th in the Network-Centric MCDA implementation ranking. This is due to the high institutional complexity of implementing such measures, which make them rather unappealing.

Similarly, “Private motor vehicle ownership restrictions” (103), which has a large number of synergies with other policy measures (Figure 5-18) and is ranked 2nd in terms of performance in the Traditional MCDA ranking, is only ranked 17th in the network-centric ranking and is not so attractive, especially considering that it is almost the most complicated policy measure to implement. This policy measure ranked 37th and 36th in the traditional and network-centric implementation complexity rankings.

5.3.4. Conclusion

In this case study, the methodology for the analysis and ranking of policy measures was applied to the policy to promote walking and cycling in cities. The methodology allows policy-makers to systematically consider a large number of measures in dealing with a specific policy objective and to gain a better understanding of the potential effectiveness and implementation complexity of each measure, on its own and when considered together with other measures within a policy package. The methodology relies on the application of network theory and MCDA approaches and facilitates policy design and policy effectiveness.

An innovative aspect of the methodology is the definition and identification of five types of relations between policy measures and their application when selecting measures for implementation. In addition, the methodology allows policy-makers or

analysts to consider and input data in a systematic way for pairs of measures; this is especially important when a large number of measures are considered. It also provides a visualization of the network of relations between all measures and a ranking of policy measures to assist in their analysis and selection for implementation and to improve the understanding of the alternatives within a region of the decision space much larger than is otherwise possible. Alongside the focus on the expected effectiveness of one or more policy measures, emphasis is also placed on the policy measures' implementation attributes. Overall, the methodology allows the consideration of additional information (relations between measures and implementation attributes) to that traditionally considered, while also simplifying the analysis through visualization and ranking. A large amount of vital information can be gleaned from the visualization of the policy measures network, information which might be overlooked otherwise simply due to the difficulty in grasping the multiple links between policy measures. Moreover, the use of the policy measure networks has also been demonstrated in the formulation of policies in ABM systems (Taeihagh and Banares-Alcantara, 2010, Taeihagh et al., 2011a). The methodology can clearly increase the understanding of the analysis and its results and thus the level of 'knowledge utilization' in the policy process (Landry et al., 2001).

The methodology is entirely based on the analysts' expertise and is generic in nature, making it relevant for any policy circumstances (local, regional, national, etc.) and policy domain (transport, energy, water, etc.). It is seen as an essential first step in the formulation of policy packages. In no way does the methodology replace policy-makers. They still need to 'bring together' the understanding gained from considering each of the networks separately, combining this with information on the characteristics of each measure as reflected in its rank and with respect to the performance and implementation dimensions (which together can be considered to represent a measure's efficiency – Givoni et al., 2010). Moreover, some of the 'hidden' undesirable properties of the measures can be exposed using the methodology. The application of the

methodology to the two case studies on policies to promote walking and cycling and emission reduction demonstrated its capabilities and advantages. The usefulness of the approach is further demonstrated by adoption of the approach in the OPTIC (2010) and VISIONS (Tight et al., 2011) EU and UK projects.

The use of computational approaches is essential to consider a larger fraction of the decision space and to fully utilize the knowledge and the experience of policy-makers. Such approaches, which support but do not replace the policy-maker in analysing and selecting individual policy measures, have been proposed in this chapter. The analysis in both case studies suggests the methodology is useful in dealing with a large number of policy measures (123 in the first case and 38 in the second), which already represent a much larger section of the decision space than would otherwise be considered.

5.4. Summary

This chapter highlighted the application of the framework and methodologies developed and discussed in chapters 3 and 4 on two case studies on UK transport-emission reduction and promotion of walking and cycling in cities. Each case study contains an introduction to the particular problem it addresses, followed by the implementation details. Results and discussion of the application of the assessment and visualization methodologies, and the conclusions reached in each case are presented.

Chapter 6

Development of the Formulation Support System

6.1. Introduction

Unlike in the cases of physical sciences and economics, the use of computational approaches in the policy realm has mainly focused on the simulation and optimization of the policy alternatives rather than on the synthesis and generation of such alternatives. A trend that increases the success of policies is the formulation of integrated policy packages, rather than a loose combination of policy measures to be considered and deployed in isolation.

In this chapter, we focus on the development of an agent-based approach to create a virtual environment for the exploration and analysis of different configurations of policy measures in order to build policy packages and test the effects of changes and uncertainties while formulating policies. The agent-based approach utilizes and

integrates techniques such as conceptual design, network analysis and MCDA. Information about the policy measures' internal properties and their interactions with other policy measures and the user preferences are used in the analysis and formulation of policies. The final decision on which policy to implement will rest with the decision-makers, who may decide to include additional policy measures or remove some of the recommended ones.

We believe that by developing systematic approaches for the formulation and analysis of policies it is possible to decompose the problem into subproblems with more manageable sizes. This allows us to analyse different alternatives in greater depth, examine more alternatives, reduce the time required for the overall analysis, and provide real-time assessment and feedback to the domain experts on the effect of changes in the configurations. This will ultimately help in forming more effective policies with synergistic and reinforcing attributes, whilst also avoiding internal contradiction. The approach is based on a previously proposed six-step framework (Taeihagh et al., 2009a).

This new approach has been applied to the formulation of policies to deal with transportation issues and emission reduction but can be extended to other domains. Our initial work was on the application of an agent-based approach in the formulation of policies (Taeihagh and Banares-Alcantara, 2010) based on the data from the VIBAT study that analysed CO₂ emission targets in the UK (Banister and Hickman, 2006b). This chapter explains the development of a generalised methodology for using an agent-based approach for the formulation of policies. We explicate the system by applying the methodology to the formulation of a policy to increase walking and cycling in Chapter 7.

Section 6.2 provides background information and explains the approach taken in this chapter in applying the previously described framework and methodologies. Section 6.3 provides a brief overview of the ABM approach, describes the architecture used and details the objectives of the approach taken. The conceptual framework used in the application of the ABM approach is presented in Section 6.4. Section 6.5 details the phases of the ABM approach and Section 6.6 details its application. Section 6.7 discusses the importance and some of the details of the use of visualizations and the GUI.

6.2. Application of the Framework and Methodologies for Policy Formulation

The major challenge faced by policy-makers is no longer lack of understanding of solutions and lack of options to implement. Given the complexity of the problems we are facing, the challenge is how to analyse and explore a large number of complex options and arrive at the best solutions given time, geographical, budgetary and a myriad of other constraints. To put the problem in perspective, in the VIBAT project 123 policy measures were considered (Banister and Hickman, 2006b) and, in the case of the VIBAT-London study, over 150 individual policy measures were identified (Hickman et al., 2010). The Visions 2030 project (used as a case study in this thesis – Tight et al., 2011) identified 142 measures to promote walking and cycling in cities. It is apparent that without having a systematic approach and tools to aid decisions, considering several options and finding suitable combinations, dealing with the large amount of information and the high level of complexity is a difficult and a daunting task if approached manually. Research has shown that capturing and processing large amounts of information is difficult for the human mind (McKee, 2003). Furthermore, Jones et al. (2009) points to evidence that excessive amounts of information can cause inertia and consideration of very few options. We believe that the traditional approach

to policy-making is not well suited for solving the twenty-first century's complex problems. The methodology for the generation of alternatives can be greatly enhanced and a systematic approach will accelerate the task of policy-making and improve policy effectiveness.

We use the proposed six-step framework described in Chapter 3 to facilitate policy formulation for achieving a set of user-defined goals and targets (Taeihagh et al., 2009a). The software system is implemented using this framework with consideration for reusability and flexibility of use with different targets, sectors and geographical scopes.

6.3. ABM Approach

6.3.1. ABM: A Brief Overview

Bonabeau (2002) defines ABM as an approach in which a system is modelled as a collection of autonomous decision-making entities called agents. Each agent individually assesses its situation and makes decisions based on a set of rules. Agents may execute various behaviours appropriate to the entity they represent. ABM allows the modelling of complex actions by the agents and reactions to other agents and to the environment, also enabling observation of the outcomes and system effects given a set of parameters (North and Macal 2007). As a result, ABM systems are well suited for exploring complex system states in which nonlinear and adaptive interactions happen (Srblijinovic and Skunca, 2003). These system states might not be otherwise explored due to their complexity. These considerations can make decision-making more successful and allow the observation of these systems' effects and their anticipation prior to the implementation of policies. As Lesser (1999) points out, multi-agent

systems are reliable, scalable and modular, which are all desirable features to have when formulating policies.

6.3.2. System Architecture and Implementation Environment

Figure 6-1 illustrates the software architecture of the DSS. The Java programming language (Java, 2008) has been chosen for the development because of its characteristics of platform independence, automatic memory management and access to an extensive library of freely available code and software. Analyses performed on the network of relations among policy measures are outputted to Excel files, which are, in turn, imported by the agent-based toolkit. The agent-based toolkit used for the analysis is Repast Simphony (Recursive Porous Agent Simulation Toolkit, North et al., 2005).

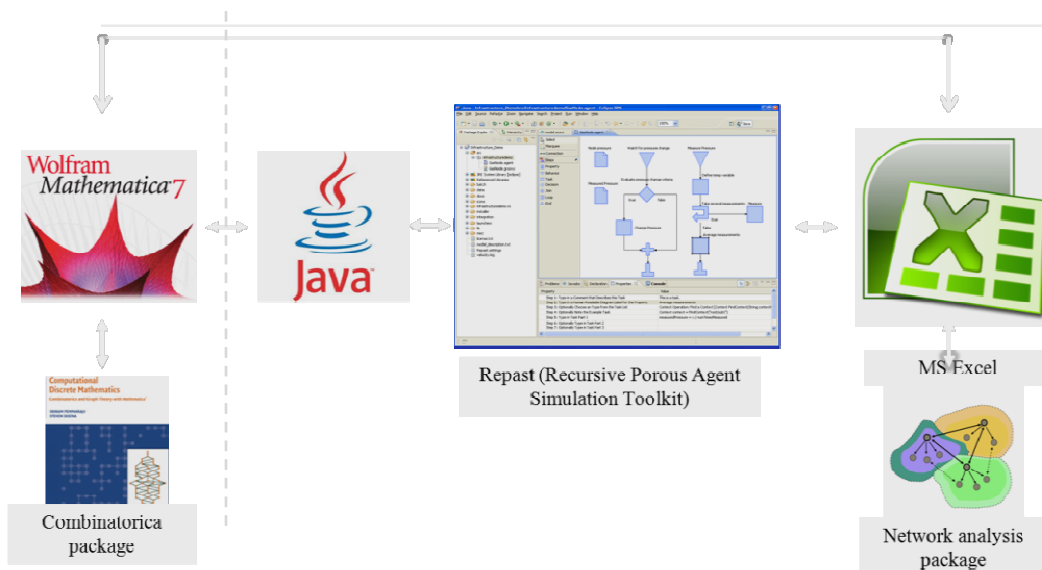


Figure 6-1 Software architecture of the DSS

6.3.3. Objectives of the Agent-Based Formulation System

For some time, virtual environments have been used for the analysis and improved understanding of complex systems such as markets. Developing such virtual

laboratories enables testing of different regulatory and market structures, e.g. the Electricity Markets Complex Adaptive Systems model developed by Argonne National Laboratory (North et al., 2002) . Our focus is on the development of an agent-based approach to create a virtual environment for the exploration and analysis of different configurations of policy measures in order to build and assess policy packages and to carry out tests to observe the effects of changes and uncertainties in policy formulation. The only somewhat similar policy formulation support tool is GB-QUEST (Carmichael et al., 2004), which focuses on a small and fixed library of policy measures and a set of predetermined combinations (this support tool does not use an ABM approach).

Although the system does not provide adaptation and learning abilities in the agents, the reasons for adopting an agent-based approach are: (a) the possibility to combine top-down and bottom-up approaches; (b) the possibility to develop flexible systems that can handle incremental discovery, design and development (North and Macal, 2007); (c) the ability to decompose the overall problem and, through the use of a multi-layered approach, accommodate abstraction and the use of hierarchical structures (similar to the hierarchical design procedure (Douglas, 1988)); and (d) the ability to deal with the organizational relationships found in complex systems (Jennings, 2000). The addition of adaptation and learning capabilities to the agents is viewed as part of the future work.

As demonstrated above, there is a plethora of reasons for choosing an agent-based approach; however, one of the prodigious advantages of using ABM is the flexibility it provides in dealing with different types of data. This is especially important in cases where qualitative information is abundant and quantification and use of this qualitative data at hand is not possible or perhaps questionable.

The proposed system has been designed to be open so that data can be added at any time and not be a limiting factor. This effectively allows the user to adopt the design

approach (advocated by strategic thinkers such as Ansoff (1991)) or the organizational learning approach (advocated by Mintzber (1990) for strategic thinking). The user can first develop the system with the best available information and then has the possibility to enhance it further as knowledge about the subject matter increases. It would also be possible to use the system earlier in the design process (with partial data) in order to understand the complexities involved.

It is worth emphasising that in this ABM system the authors are more interested in exploring and tackling the technical problems resulting from the complexity in policy formulation and in showcasing the use of a computational framework rather than in exploring or simulating human behaviour in decision-making. Therefore, using agent architectures such as BDI (Bratman et al., 1988 and Rao and Georgeff, 1995) or PECS (Urban, 2000) is not the focus of this research, although they are relevant from a social science perspective.

6.4. Conceptual Framework

In the ABM system, a Model Initialiser agent carries out the task of reading the required information to generate different agents and develop networks that represent the interactions among them. Policy Packer agents undertake the selection of policy measures to create the policy packages. Assessor agents evaluate the alternatives based on the given criteria, rank them at different hierarchical levels and provide real-time feedback to agents to help them in their decision-making processes. When focusing on the creation of policies rather than packages, it is possible to use Policy Clusterer agents to combine packages and finally have a higher set of Policy Selector agents that form alternative future images using the outcomes from the Policy Clusterers. Figure 6-2 illustrates a conceptual ABM framework for the formulation of policies.

The initial data required are the details of the available policy measures and their interactions that are read from an Excel file and a set of preferences that are acquired from the user as global parameters and through a GUI.

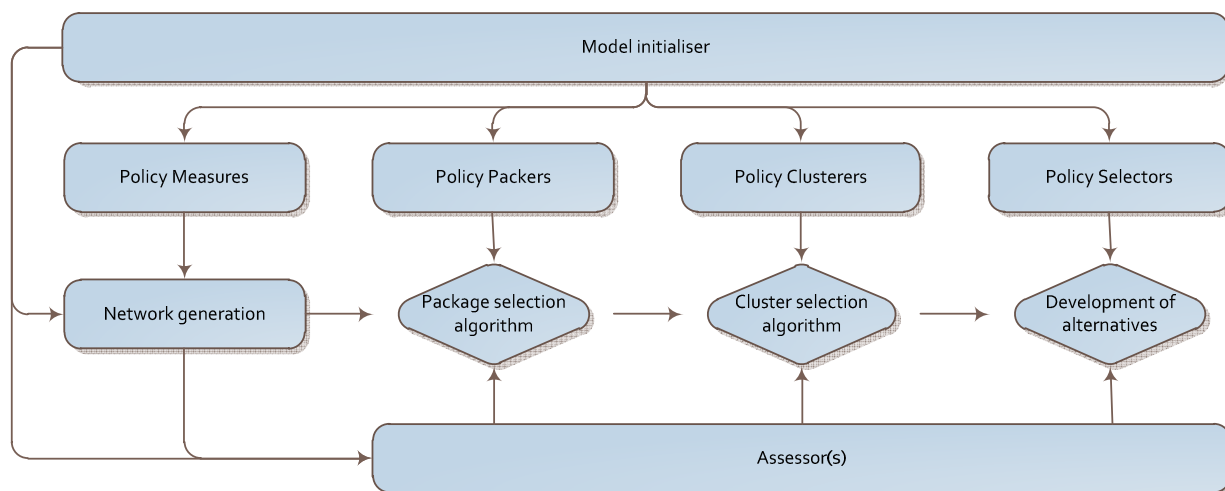


Figure 6-2 Overall conceptual ABM framework for policy formulation

6.5. ABM Phases

Figure 6-3 illustrates different phases of the ABM implementation using the Repast Symphony ABM Toolkit (North et al., 2005):

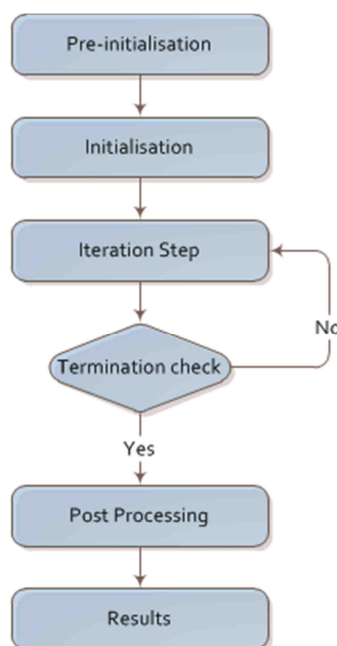


Figure 6-3 ABM phases

- 1) Pre-initialisation: in this step, the structure of the score file (the overall meta-structuring of the agents, their properties, grid and global parameters (Figure 6-4)) is developed and the runtime environment is set up. The Repast Symphony's runtime environment contains a scenario tree that shows various aspects of the system (data loader, data sets, displays, charts, outputters, etc. – see Figure 6-4).
- 2) Initialisation: in the initialisation phase, the Model Initialiser agent is created. This in turn creates various agents used in the system, assigns their properties and forms networks of interactions among them.
- 3) Iteration steps: while the termination criterion has not been reached, different types of agents perform their assigned tasks at each time step (e.g. make decisions according to their algorithms, pass on information to each other, assess different types of agents, etc.) or perform special routines when conditions are met.
- 4) Post processing: in this step, analysis of the charts and data collected during the simulation and the initial validation of the simulation results are carried out.

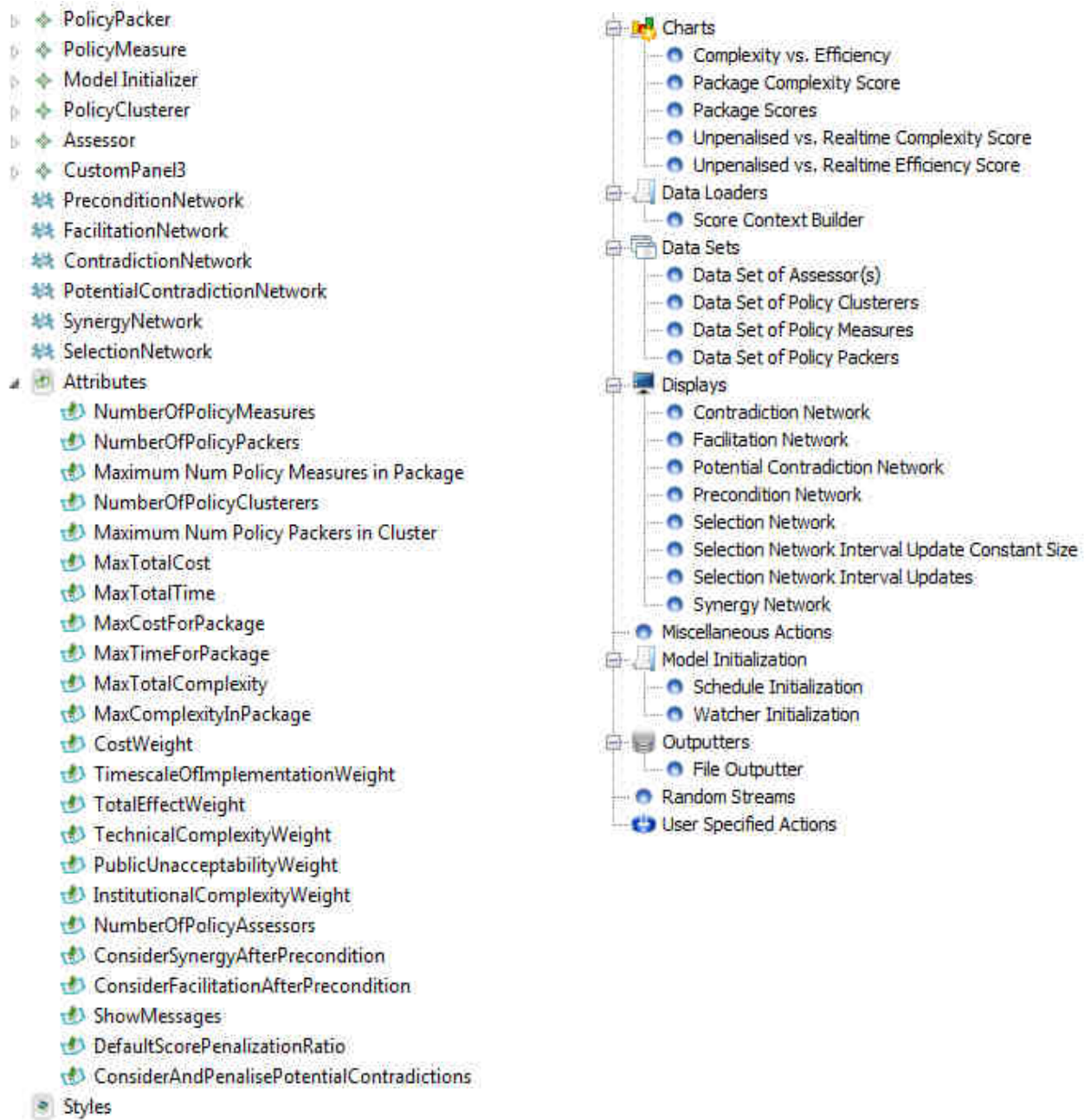


Figure 6-4 Score File (Left) and Scenario Tree (Right)

6.6. Details of the Agent-Based Approach

Repast Runtime (North et al., 2005) uses a meta-structuring file called the “score file” to manage user-defined agents, their structural relations and the global parameters used in the system (Figure 6-4). Moreover, Repast Symphony’s runtime agent editor provides a range of facilities that includes:

- (a) Creation, cloning and deletion of different types of agents during runtime;
- (b) Provision of lists of existing agents and their connections;
- (c) Selection of the agents and change of their properties during runtime;
- (d) The ability to take snapshots or video while the system is running; and
- (e) Creation or deletion of links between agents in different network structures.

The rest of this section details the four types of agents used for the formulation of policy packages:

- Model Initialiser: generation of the agents and development of the networks;
- Policy Packer: creation of policy packages;
- PPScheduler: scheduling of Policy Packer agents; and
- Assessor: evaluation of the policy packages.

6.6.1. Initialisation Process and Model Initialiser Agent

The Model Initialiser agent is scheduled to start at the beginning of the simulation run and carry out the initialisation tasks. These include the creation of the agents, assignment of their properties, creation of networks of interactions among policy measures (i.e. network projections, created using the Jung Network/Graph Library (O'Madadhain et al., 2005)) and the definition of the structural relations between different agents and networks in the system. Retrieval of the policy measure properties and interaction data from the Excel files was carried out using the JExcel Java library (Khan, 2004). Figure 6-5 depicts a simplified version of the initialisation process carried out by the Model Initialiser agent:

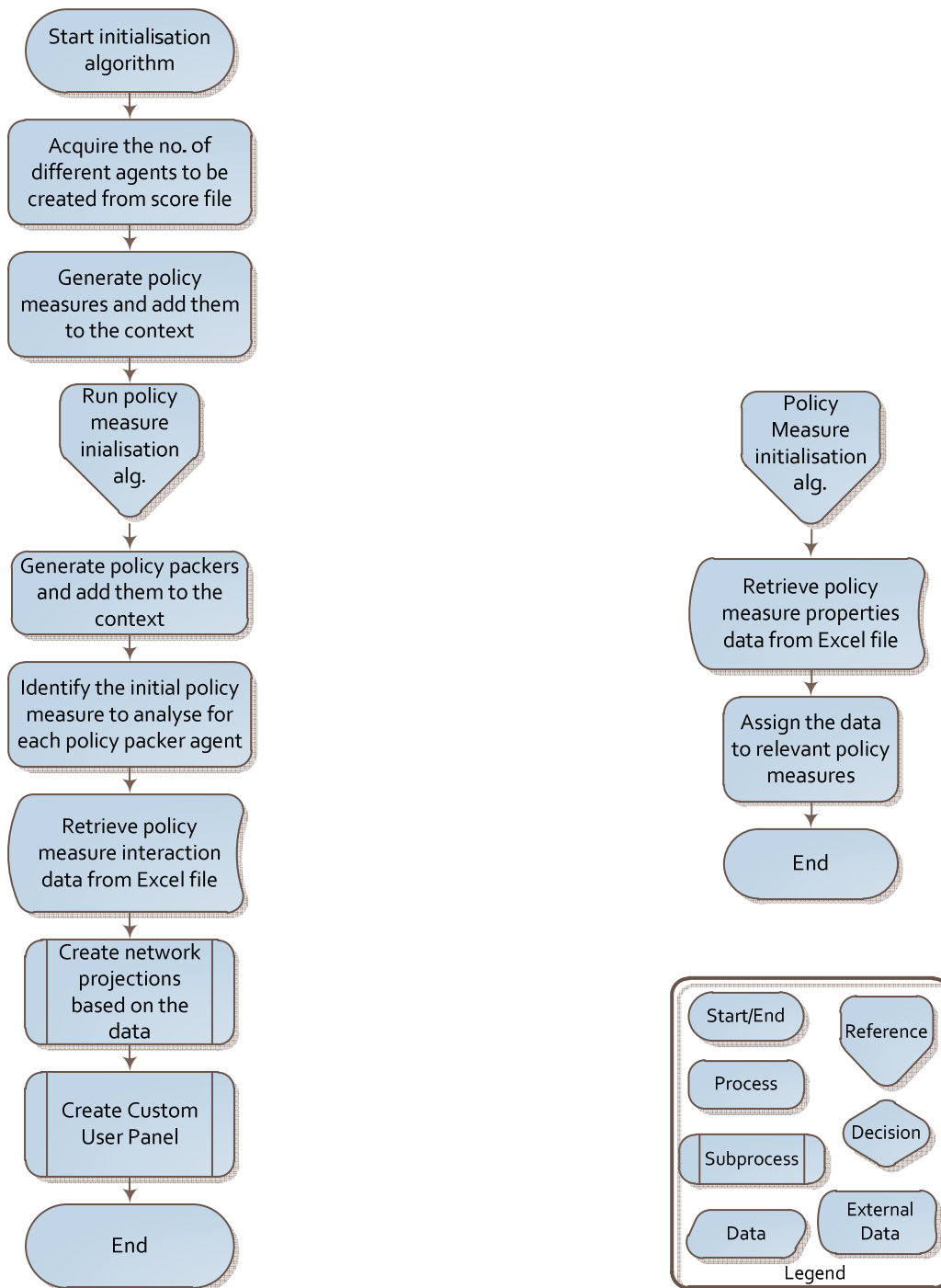


Figure 6-5 Simplified version of the initialisation process. Model Initialiser agent (left) and policy measures initialisation subprocess (right)

6.6.2. Policy Packer and PPScheduler

Policy Packer agents undertake the selection of policy measures to create policy packages. These agents can formulate policy packages using only global parameters or

user inputs (in the interactive mode). The main tasks carried out by a Policy Packer agent include:

- (a) Identification and consideration of preconditions of the policy measures under analysis;
- (b) Consideration of the different constraints imposed on the system through global parameters or via the Contradiction and Potential Contradiction networks;
- (c) Utilization of the synergy and facilitation networks to create synergy within the policy packages;
- (d) Utilization of user inputs during runtime for the formulation of policy packages; and
- (e) Assessment and update at each iteration step of the policy package properties based on the policy measures they contain. This information is used by the Assessor agent to compare the packages.

Each Policy Packer agent starts with a top measure selected on the basis of its ranking score, which is calculated through a policy measure ranking methodology (Chapter 4 and Taeihagh et al. 2009b). It is possible for the user to add additional Policy Packer agents to the system at any time. Policy Packer agents check to see if the selected policy measure has any preconditions and, in the case that it does, they are added to the package. In the next step, the highest ranked policy measure that has positive interactions (synergy or facilitation) with the measures in the package or its preconditions is identified and added. This addition (with a variety of options available to the user) can continue in successive iterations to expand the size of the packages, allowing the user to experiment with different configurations and to observe the effects on the performance of the packages.

Figure 6-6 depicts a simplified version of the decision process of the Policy Packer agents in the interactive mode. It can be seen that certain behaviours are executed when a particular circumstance is reached. In those cases where distinguishing these conditions is difficult, the desired changes in the behaviour of the agents are implemented through “watchers”. Watchers trigger certain agent behaviours when an expected circumstance occurs and can have complex scheduling and/or analysis processes to identify these circumstances. For instance, one of these watchers monitors the state of all the Policy Packer agents when they are in the precondition analysis phase. Once all of the agents have carried out their precondition analyses, the watcher triggers a change in the state of the agent that allows it to consider other aspects of the policy measure analysis. In addition, a PPScheduler agent schedules the Policy Packer agents in performing tasks that can be affected by the order in which the agents carry out their assignments.

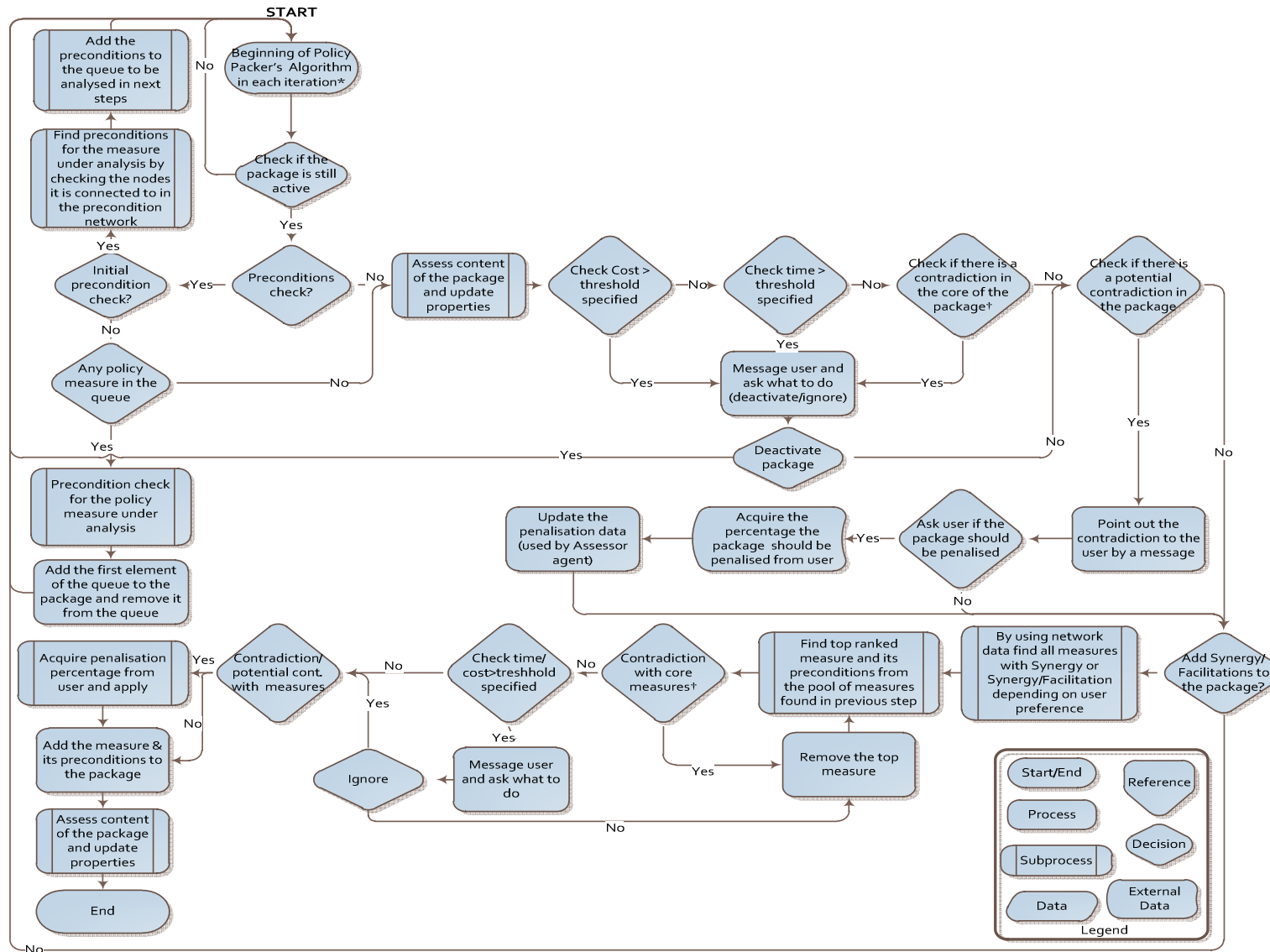


Figure 6-6 Simplified version of the Policy Packer's selection process

*when there is a reference back to the start of the algorithm the continuation of the analysis happens in the next iteration step.

†partially implemented as the implementation does not make a difference since only one contradiction relation existed in the case study.

6.6.3. The Assessor Agent

The Assessor agent evaluates the alternative policy packages based on two sets of criteria: performance (Total Cost, Total Implementation Time and Total Effect) and implementation complexity (Public Unacceptability, Technical and Institutional Complexity). Similar to the policy measure ranking described in Chapter 4, the ranking of the policy packages is carried out by the Assessor agent using MCDA methods, i.e. the weighted summation of the scores with respect to the criteria specified by the user through the GUI (discussed in Section 4.3). The Assessor agent provides real-time feedback to the user through the GUI, helping to identify the more promising packages and understand the implications of changes in different packages. Moreover, the scores are communicated to the Policy Packer agents to help them in their decision-making process. Figure 6-7 illustrates the Assessor agent's flowchart for the assessment of the packages. The Assessor agent retrieves information regarding the packages from the Policy Packer agents and uses it to rank the packages. The retrieved information includes:

- (a) Total Cost: sum of the cost of all of the policy measures in a package;
- (b) Total Implementation Time: sum of the Timescale of Implementation (TI) and the Delay (D) for the policy measures in a package;⁹
- (c) Total Effect: defined as summation of the values obtained from multiplication of the Timescale of Effect (TE) of the policy measures by their Effectiveness (E); and
- (d) In the case of Public Unacceptability, Technical Complexity and Institutional Complexity, the value associated with the package is the sum of the scores of the individual policy measures it contains.

⁹ It cannot be generically prescribed that all of the policy measures in a package can be implemented concurrently (in parallel). Therefore, in the various calculations related to timescales, the total time required for implementation is the sum of the implementation times of the policy measures (i.e. the upper bound of the implementation time).

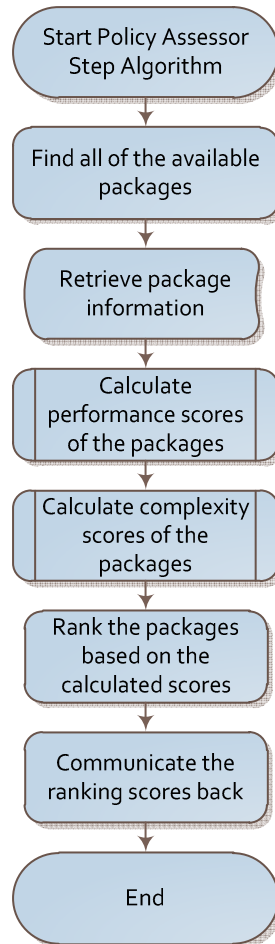


Figure 6-7 Simplified version of the assessment process applied by the Assessor agent

The ranking is based on the weighted summation of the scores of the policy measures. Weights used for the criteria in each set are specified as global parameters defined by the user and can be changed at any time during the simulation¹⁰. All the criteria in each set were assigned positive weights fixed to a sum of “1”. Every individual criterion within each set falls into one of the two categories ‘desirable’ or ‘undesirable’. A criterion is desirable when a high score is considered better (e.g. Total Effect) and is undesirable when a lower score is considered better (i.e. Cost, Total Implementation Time, Public Unacceptability, and Technical and Institutional Complexities). In the

¹⁰ The weights assigned to the criteria were based on the authors’ judgment and expertise. The weights used were: Performance ranking: Total Implementation Time 20%, Total Effect 40%, Cost 40%. Complexity ranking: Technical Complexity 20%, Public Unacceptability 40%, Institutional Complexity 40%.

first set (performance criteria), a mix of desirable and undesirable criteria is present. All the scores were transformed to desirable by using the reciprocal of the values associated with undesirable criteria (Grunig and Kuhn (2009)). The resulting scores were normalised and then multiplied by their corresponding weight (see Eq. 6.1 for desirable criteria and Eq. 6.2 for undesirable criteria).

$$sd(k) = \sum_{j=1}^d \left(\frac{c_{k,j}}{\sum_{i=1}^p c_{i,j}} \times w_j \right) \quad \text{Eq. 6.1}$$

where:

$sd(k)$: Score of the policy package k with respect to the desirable criteria

d : Number of desirable criteria

p : Number of policy packages

$c_{i,j}$: Score of the policy package i with respect to criterion j

w_j : Weight assigned to criterion j

$$su(k) = \sum_{j=1}^u \left(\frac{\frac{1}{c_{k,j}}}{\sum_{i=1}^p \frac{1}{c_{i,j}}} \times w_j \right) \quad \text{Eq.6.2}$$

where:

$su(k)$: Score of the policy package k with respect to the undesirable criteria

u : Number of undesirable criteria

p : Number of policy packages

$c_{i,j}$: Score of the policy package i with respect to criterion j

w_j : Weight assigned to criterion j

The performance score is calculated by adding the policy packages' scores across both desirable and undesirable categories. Hence, the policy package with the highest score in the first set is ranked as the top policy package in terms of performance (Eq. 6.3).

$$\text{Performance score of the policy package } k = sd(k) + su(k) \quad \text{Eq. 6.3}$$

As all of the criteria in the second set (implementation complexity criteria) are undesirable, there is no need to convert the undesirable criteria to desirable and the package with the lowest score (lowest level of complexity) is simply the top-ranked policy package with respect to implementation complexity (Eq. 6.4).

$$\text{Implementation complexity score of the policy package } k = \sum_{j=1}^m \left(\frac{c_{k,j}}{\sum_{i=1}^p c_{i,j}} \times w_j \right)$$

Eq. 6.4

where:

- m : Number of criteria
- $c_{i,j}$: Score of the policy package i with respect to criterion j
- p : Number of policy packages
- w_j : Weight assigned to criterion j

6.7. Visualization and GUI

Due to the level of complexity in the interactions among policy measures in different networks, provision for a variety of visualization options is essential. Different visualizations illustrate the networks of policy measure interactions, and the policy packages with the policy measures they contain. In addition, various data sets are used for collecting data from different agents in each iteration step. By using the data sets, we can develop various charts depicting the evolution of various properties of the agents during the formulation process, such as Performance Score vs. Time, Complexity Score vs. Time, or Performance vs. Complexity Score. Some of the details of the

visualizations are presented in the rest of this section and the results of their application are presented in Chapter 7. Figure 6-8 is a screenshot of the GUI of the system. Aside from the simulation run options and global parameter tabs, a user panel is also embedded in the same area (see tabs at the bottom of the left panel) and a variety of network visualizations and charts (central and right panels) are presented to the user through the GUI. The central panel in Figure 6-8 illustrates the precondition relation network among policy measures. All of the networks can be visualized using a variety of network visualization algorithms, and network data (nodes and edges) can be manipulated by the user. The panel on the right presents the evolution of the policy packages' properties, which is updated in each iteration step.

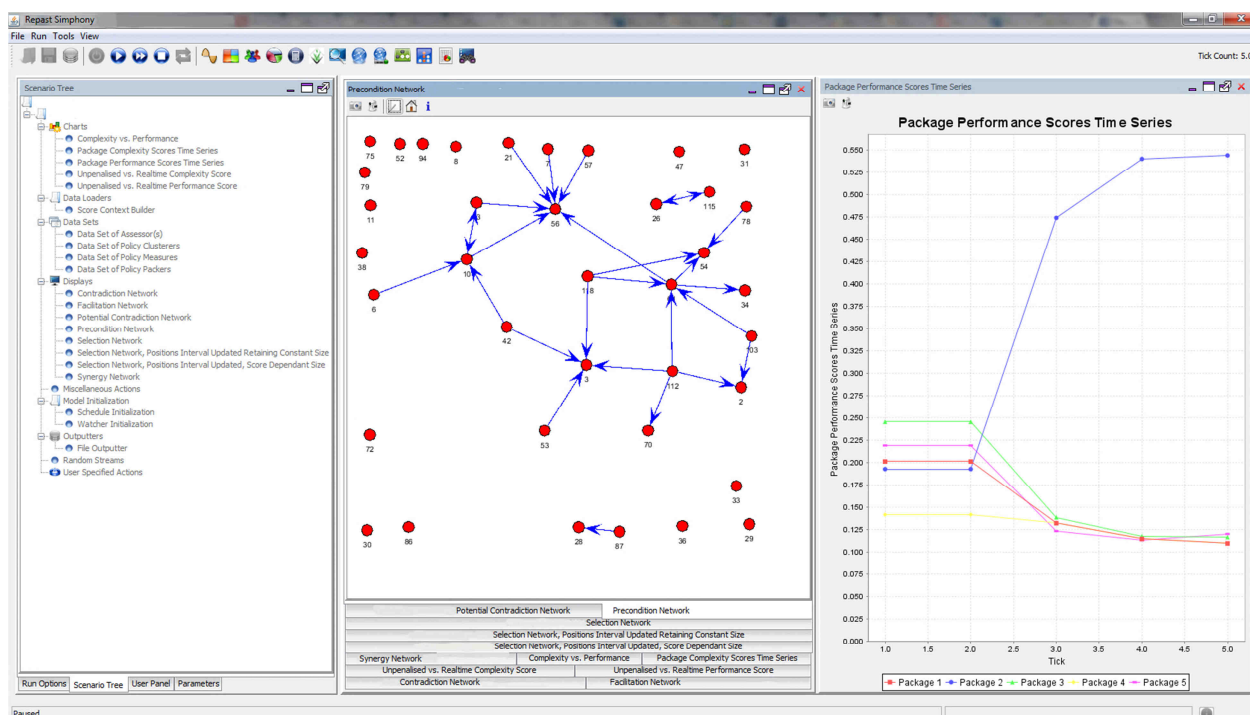


Figure 6-8 Screenshot of the policy formulation GUI

The development of complex technical systems is often not the main expertise of policy-makers. This factor should not be neglected when developing DSSs in this domain. As the experience of the authors shows, an important factor in the acceptance and use of such systems is their level of transparency; domain experts should be

empowered by the tools. This issue boils down to getting policy-makers to trust that there are no hidden parameters/features that affect the outcome produced by the system and that they are in control, not the machine. Furthermore, another important feature that helps in the adoption and use of the system, aside from providing a detailed explanation of the steps taken, is providing the ability to interact with the system. It is essential to give policy-makers the ability to make changes to the assumptions and data “on the fly” and offer various override features that allow the user to carry out adjustments on different aspects of the decision algorithm. Providing the user with the ability to intervene and make changes or provide feedback can be crucial in those cases where the policy measure’s properties or its requirements are context specific.

Aside from the features that Repast Symphony’s runtime agent editor provides (Section 6.6), a custom panel was added based on feedback from the domain experts. This panel provides detailed information about individual packages, the policy measures they contain and those that are outside of the package. When a policy package is selected, a list containing all of its policy measures is shown and, by selecting an individual policy measure within the list, all of the interactions of that particular policy measure are presented to the user. In addition, the ability to add/remove policy measures to/from policy packages was added to the custom panel.

Moreover, an interactive mode has also been developed. In this mode, agents rely on the user input for a variety of decisions. For instance, when the cost, time or size of a policy package has exceeded the acceptable threshold or a potential contradictions exist, the agents do not use the default values in the system and prompt the user for input on whether to deactivate or penalize a package (and by what percentage).

The source code of all of the previously described aspects of the ABM approach and its application in formulations polices for promotion of walking and cycling is presented in Appendix A.9.

6.8. Summary

In Chapter 6, the development of an agent-based approach to create a virtual environment for the exploration and analysis of different configurations of measures for policy formulation was discussed. An overview of the ABM paradigm was presented and this was followed by the details of the system architecture and the objectives of using such an approach for policy formulation. A conceptual framework for using such a system was presented and subsequently the details regarding the implementation of the system based on the framework and methodologies discussed in chapters 3 and 4 were presented. The roles that different agents and processes play were illustrated. Finally, the importance of the use of visualizations and the GUI for supporting the policy-makers in such systems were discussed. In Chapter 7, we describe the application of the ABM approach in the promotion of walking and cycling in cities, providing details of the input data and the results achieved.

Chapter 7

Application of the Agent-Based Approach in the Formulation of Policy Packages for Promotion of Walking and Cycling in Cities

7.1. Introduction

The importance and nature of transport policy makes it especially difficult to address (e.g. Ney, 2009). As mentioned in Chapter 5, in sustainable transport policy a major objective is to facilitate a shift from the use of motorized to non-motorized transportation, which can be translated as increasing the level of walking and cycling (see for example Boarnet (2006) and Rietveld and Daniel (2004)). The “Visions of the role of walking and cycling in 2030” research project (Tight et al., 2011) seeks to develop and evaluate alternative visions in which walking and cycling play a more

central role in urban transportation by the year 2030. It is understood that a combination of policy measures (policy packaging) is necessary to support the shift from motorized to non-motorized transportation, i.e. an increase in walking and cycling.

In this chapter, we describe the approach taken in applying the development of a virtual environment to build and assess policy packages (described in Chapter 6) for the promotion of walking and cycling (based on the input data gathered in the second case study in Chapter 5) and to observe the effects of changes and uncertainties on the formulated policy packages. In Section 7.2, details of the input data used by the system are provided and Section 7.3 details the results achieved from the implementation of the agent-based approach to the promotion of walking and cycling in cities. In Section 7.4, the conclusions are presented.

7.2. Input Data

7.2.1. Policy Measure Properties

Thirty-eight policy measures that promote walking and cycling constitute the core of the library of policy measures used in the system. The repository was created from the Visions 2030 project (Tight et al., 2011) through the participation of domain experts and the use of scientific literature. These policy measures have different natures and characteristics; some can be expressed quantitatively but the majority are of a qualitative nature. These properties and their assessment were discussed in detail in Section 5.3.2:

- Cost (C)
- Effectiveness (E)
- Timescale of implementation (TI)
- Delay (D)
- Timescale of Effect (TE)
- Technical Complexity (TC)
- Public Unacceptability (PU)
- Institutional Complexity (IC)

7.2.2. Policy Measure Interactions and Initial Ranks

As described in Chapter 4, once a library of policy measures and their properties have been developed, the first step in the analysis is to study, identify and formalize relations that capture the policy measure interactions. Five types of interactions between the policy measures were identified: Precondition, Facilitation, Synergy, Potential Contradiction and Contradiction (see Section 4.3.1 for definitions). The classification of the policy measures' interactions was carried out by domain experts and stored in an adjacency matrix in an Excel file (see Section 4.3.2). The multi-relational adjacency matrix is read from the Excel file and, during the initialisation phase of the ABM system, used to form network structures which only entail a single type of relation (in the case under study, five networks). These networks are visualized and used in the formulation and analysis of policy packages. The rank of the policy measures is obtained during the initialisation step and is used to differentiate between them.

7.3. Results from the Application of the Agent-Based Approach

7.3.1. Development of Policy Packages

The ABM system provides a virtual environment with the ability to explore, formulate and analyse different configurations of policy measures in order to build policy packages, and to test the effects of changes made to the policy packages. The outputs from the ABM are the formulated policy packages, which can be used independently or in the development of wider policies that address broader objectives.

Figure 7-1 is an illustrative example of a set of policy packages that have been created by the system. Each green circle represents a Policy Packer agent and the blue circles connected to it represent the policy measures it has selected to build a package. In order to simplify the explanation and visualization of the policy packages in this example, the number of policy packages has been limited to five and the number of time steps to three. Table 7-1 presents the top policy measures.

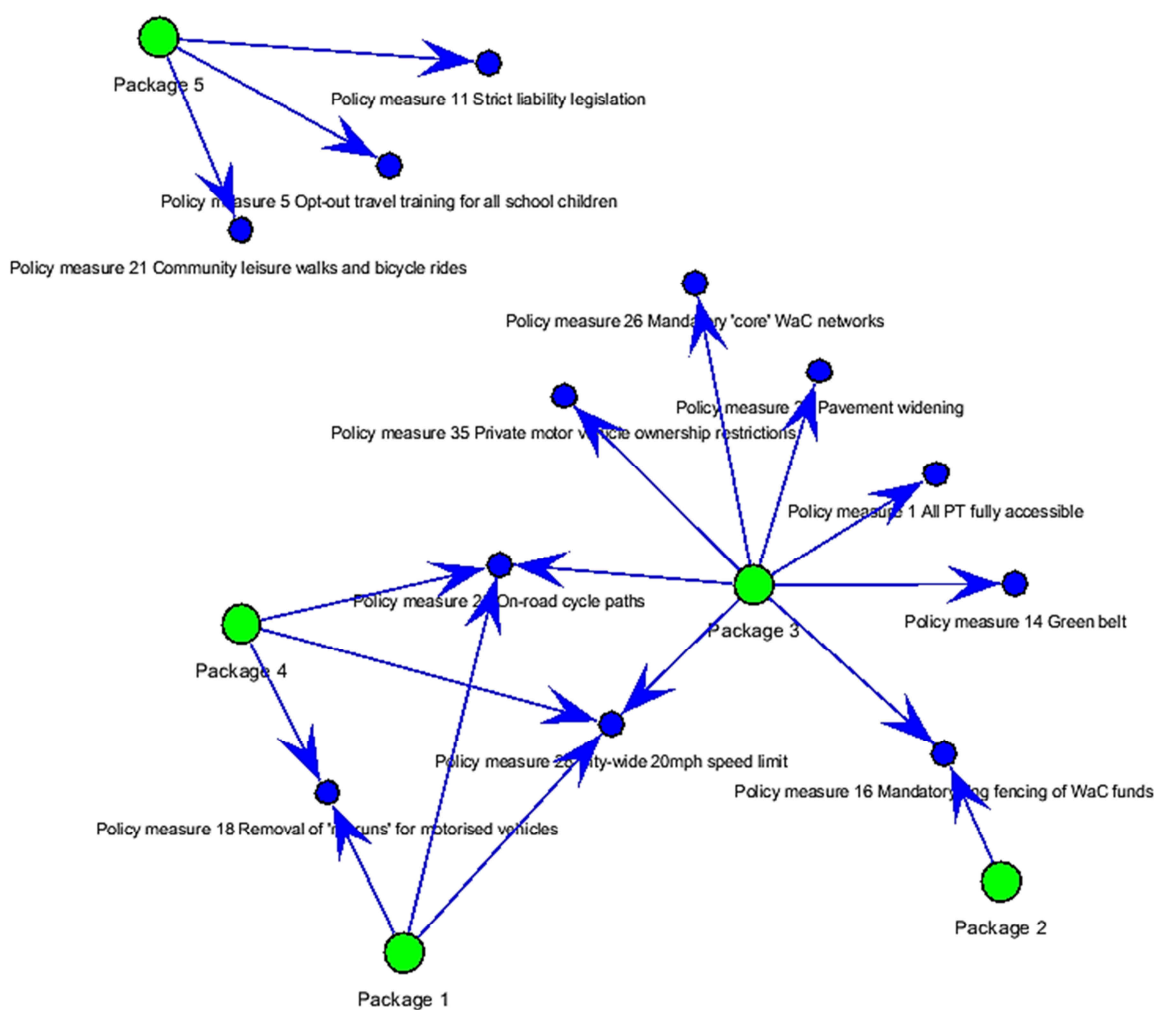


Figure 7-1 A sample of policy packages created by the Policy Packer agents

Table 7-1 List of top policy measures used by Policy Packer agents

Policy Packer number	Top policy measure in the package
1	Policy measure 28 City-wide 20mph speed limit
2	Policy measure 16 Mandatory ringfencing of WaC funds
3	Policy measure 14 Green belt
4	Policy measure 18 Removal of 'rat runs' for motorized vehicles
5	Policy measure 11 Strict liability legislation

For example, policy measure 14 (“Green belts”) is the starting point of Package 3 because it is the highest-ranking measure available (after the first two have been used to initialise packages 1 and 2; different policy packages may contain common policy measures, but we preferred to initialise the five packages using a different policy measure). Policy measure 14 is ranked highly because of its low cost, high effectiveness, high duration of effects after implementation, and because it has no preconditions. It is evident that the introduction of green belts can play an important role in the promotion of walking and cycling as they stop the expansion of cities and thus help in stopping the increase of average travel distances.

Other measures are then added to the package because they either have synergy or facilitation relations with the policy measures already in the package. Policy measure 35 (“introduction of private motor vehicle ownership restrictions”) was selected on this basis. Policy measures added to a package are checked for their preconditions and, if such relations exist, they are also added to the packages. Policy measures 26 (“Mandatory 'core' walking and cycling networks”) and 1 (“All public transport fully accessible”) were identified as preconditions to policy measure 35 and thus were added to the package. This process is carried out iteratively until no further precondition exists for the measures within a package. It is for this reason that policy measures 16 (“Mandatory ringfencing of WaC funds”), 23 (“On-road cycle paths”) and 24 (“Pavement widening”) were added following the addition of policy measures 26 and 1. Lastly, after addition of policy measure 35 and its preconditions, the next best policy

measure with synergistic relation is policy measure 28 (“20 mph speed limit”), which has no preconditions. A 20 mph speed limit makes it safer to walk and cycle and discourages the use of private vehicles.

Figure 7-1 also illustrates that packages 1 and 4 converged and are identical. Package 1 was started by considering policy measure 28 (“City-wide 20 mph speed limit”) and package 4 by considering policy measure 18 (“Removal of 'rat runs' for motorized vehicles”). After the selection of the top policy measure, the Policy Packer agents look for synergistic relations with the top policy measures and choose the highest ranked in order to enhance the package. The top policy measures for both of these packages are synergistic and thus they are added (i.e. policy measure 18 is added to package 1 and policy measure 28 to package 4). Furthermore, at the next iteration step both packages have had the same set of synergy options and have chosen policy measure 23 (“On-road cycle paths”) to be added to their packages. As a result, these two packages have converged to the same set of nodes.

Finally, in the case of policy package 5, policy measure 11 (“Strict liability legislation”) constitutes the core of the package and policy measures 21 (“Community leisure walks and bicycle rides”) and 5 (“Opt-out travel training for all school children”) have been added because of their synergy with policy measure 11.

7.3.2. Visualization of the Assessment Data

As described in Section 6.6.3, at every iteration step the Assessor agent calculates the performance and complexity scores of the packages. Figures 7-2 and 7-3 present the evolution of the performance and the complexity scores of the five policy packages over a short number of iterations. Figure 7-2 shows that the addition of policy measures in the second iteration greatly increased the performance of policy package 3. However,

further additions in the third iteration decreased its performance. Figure 7-3 shows a monotonic increase in the complexity of all policy packages. It can be seen that while addition of policy measures to package 3 in the second iteration increases the performance of the policy package, it also greatly increases the complexity of this package in comparison to other packages. The change in the ranking of the policy packages is dependent on the policy measure being added to the package at each iteration step and on its requirements (preconditions). Not all of the policy packages behave in the same way. The addition of a synergistic policy measure to policy package 5 in the second iteration step decreases its performance score but increases its complexity (although only very slightly).

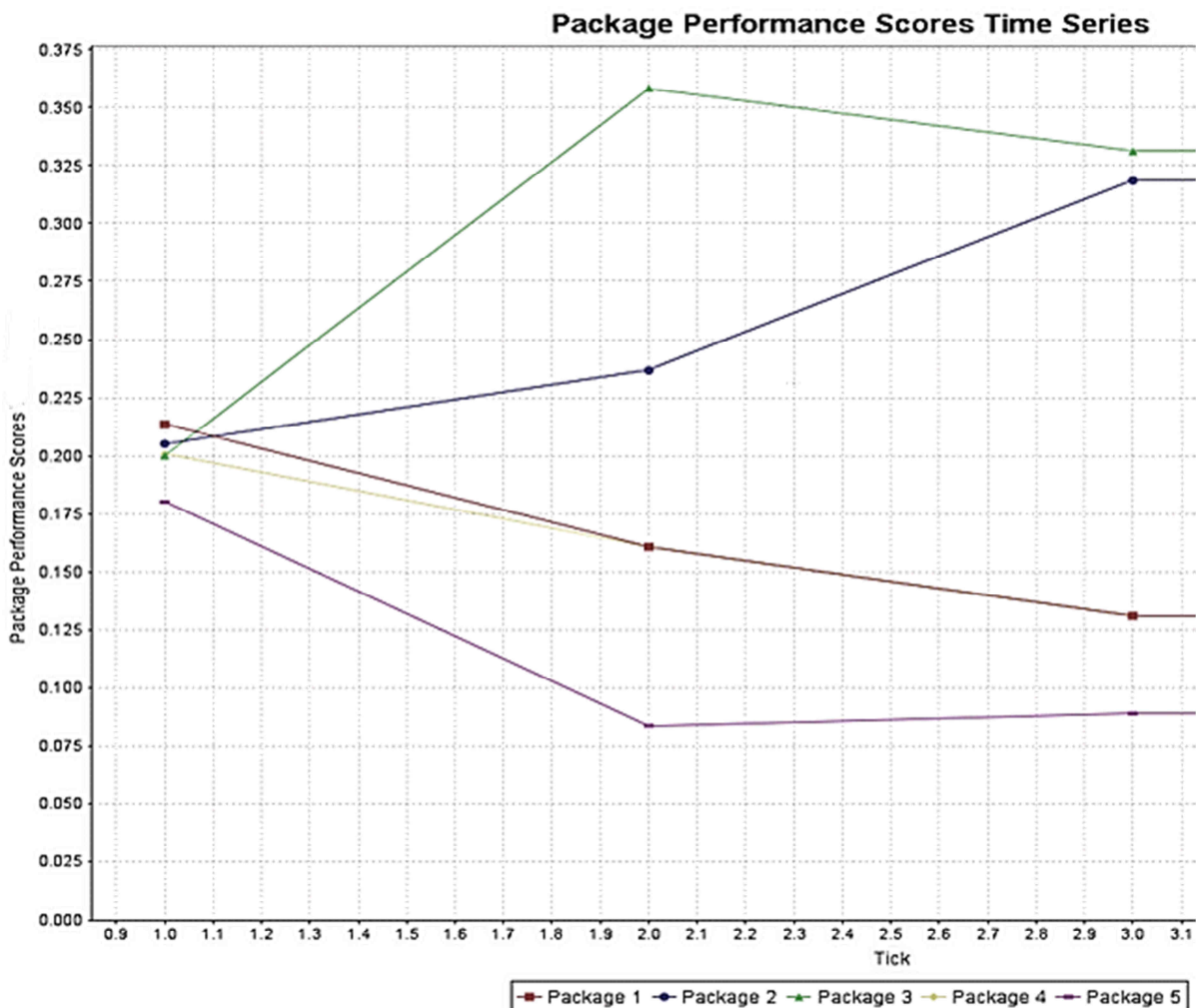


Figure 7-2 Package Performance Scores

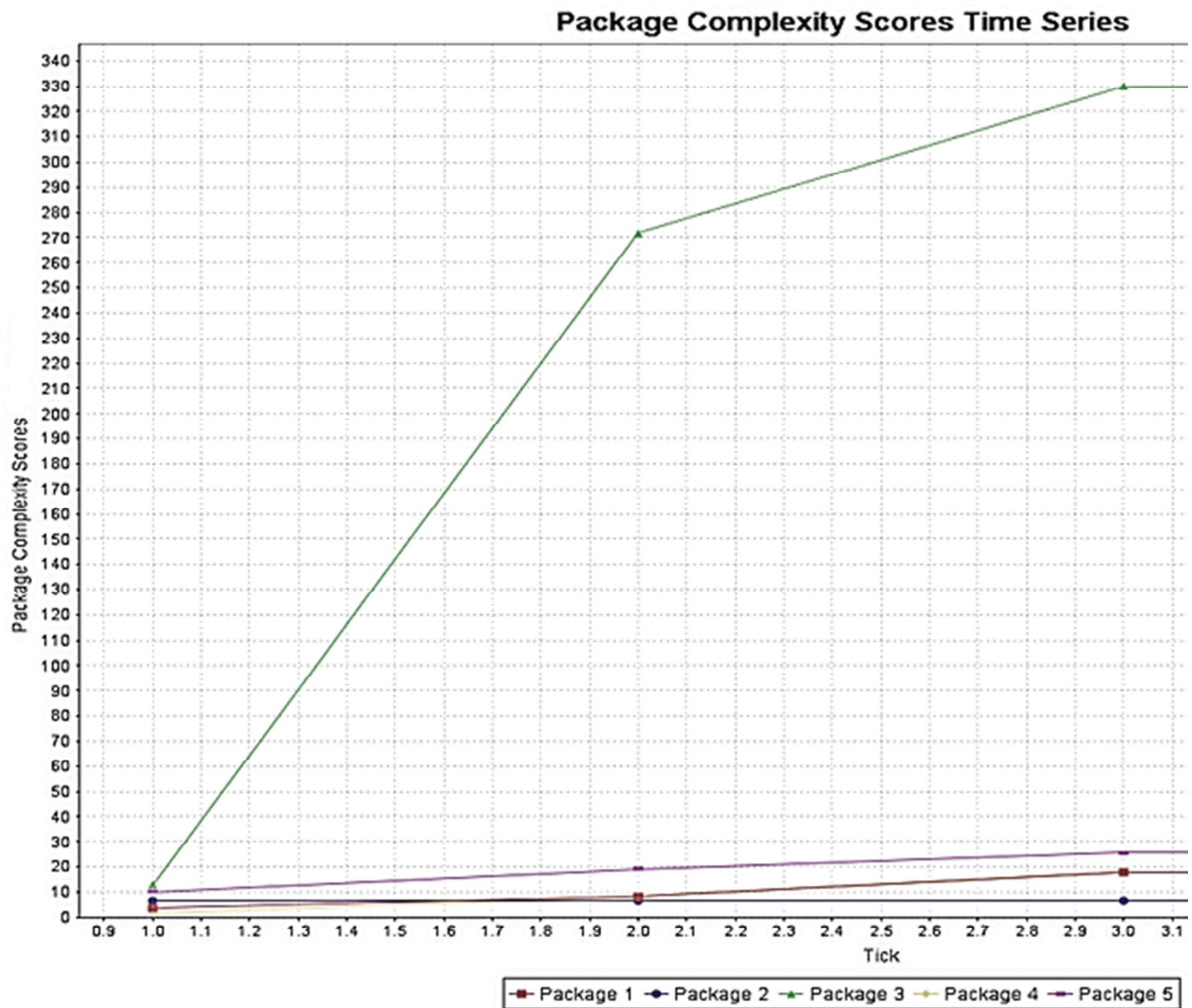


Figure 7-3 Package Complexity Scores

Package 2 is a special case. Its top policy measure does not have preconditions or synergistic relations. Therefore, it has remained isolated. Although it is evident that policy package 2 has had no addition of policy measures during the iteration steps (visible in Figure 7-1), it had a change in performance. The reason is that the performance score of the policy packages is relative to other packages. Figure 7-4 illustrates the complexity versus the performance scores for the packages.

Unlike performance scores, the complexity scores can only increase with the addition of policy measures. The best policy packages will be located in the bottom right corner,

where performance is at the maximum and complexity minimum. This visualization enables the user to quickly identify the effect of changes to the packages and the package “sweet-spots”. Using this and other relevant information, experts can form better opinions on the optimal size of a package. It is evident from Figure 7-4 that policy package 3 has the highest performance in comparison to other packages but that this comes at the cost of an excessive level of institutional complexity. Furthermore, by analysing the final step, it is evident that it has a negative effect in the performance score and also results in an increase of the complexity of the package.

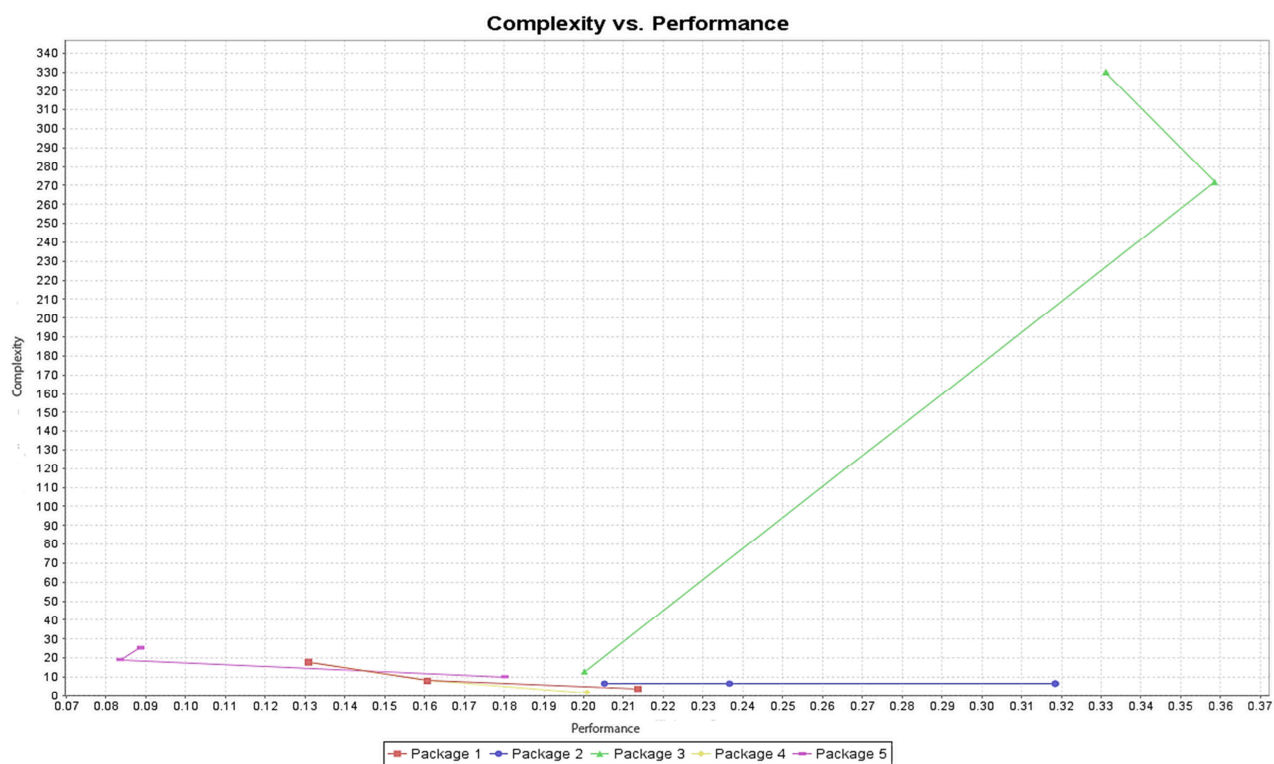


Figure 7-4 Complexity Score vs. Performance Score

In order to provide more visual cues, the performance and complexity scores can be incorporated in the visualization of the policy packages. The size of the green circles (Policy Packer agents) in Figure 7-5 is adjusted based on the performance scores of the individual packages. The size is based on a scaling factor. For instance, a scaling factor

of 15 would result in the Policy Packer with the highest score having an icon size 15 times the smallest one.

7.3.3. Scalability of the System

One of the benefits of using the system is the ability to analyse and explore a larger number of options in parallel at no extra cost, as is shown in Figure 7-5. This is particularly important in tasks such as policy formulation where complex interactions exist and experts are not able to recall all the crucial information at the right time and have difficulties judging the effects of changes to the data. A support system such as the one discussed in this thesis can play a crucial role in providing real-time feedback to the user and help in comparing different policy packages and identifying optimal configurations.

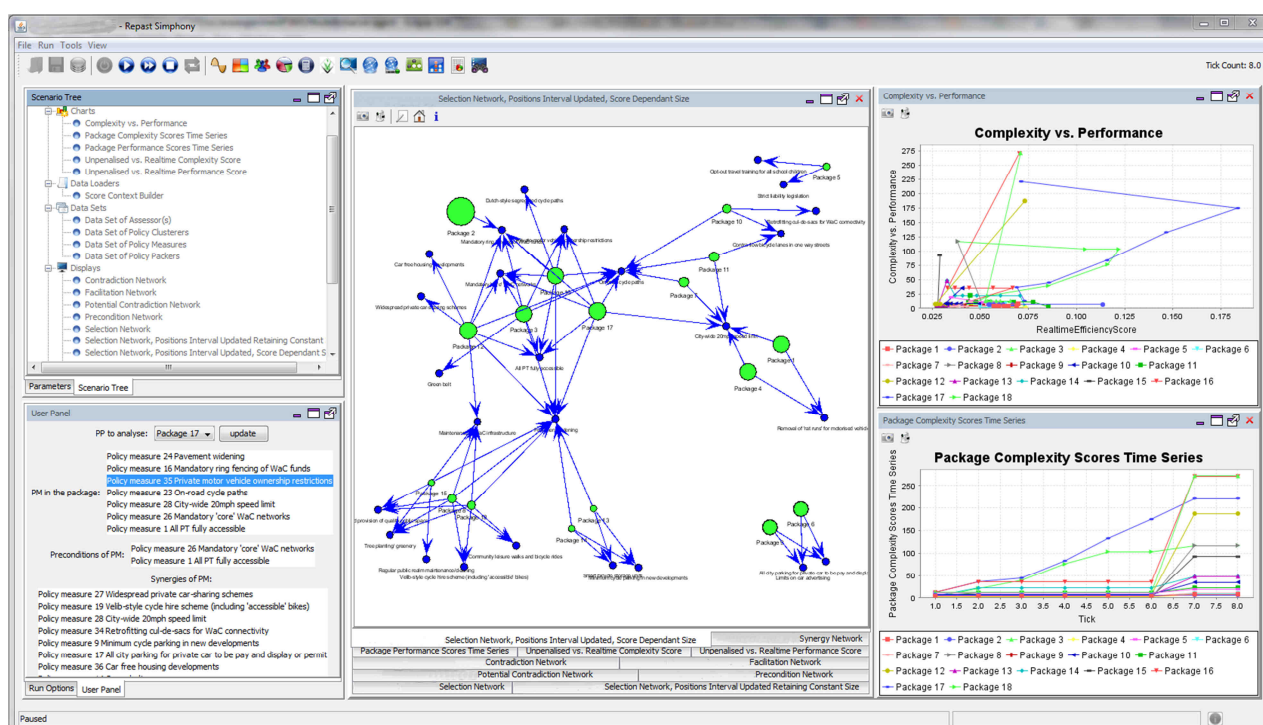


Figure 7-5 Generation of a large number of policy packages

Figure 7-6 highlights how the visual cues and the feedback from the Assessor agent can be used to inform the experts exploring large and/or complex sets of policy packages. The visualization was done using the Fruchterman and Reingold algorithm (1991), which positions the most connected nodes in the centre of the visualization. The policy measures (blue nodes) that are highly connected to the Policy Packer agents (green nodes) are placed in the centre of the network; they play a crucial role in the implementation of a large number of policy packages. For example, pavement widening is one such policy measure that has been selected by half of the policy packages in Figure 7-6. In turn, Policy Packer agents (green nodes) that are centrally located depend on a larger number of policy measures and typically have a high level of complexity. As mentioned earlier, the size of the green nodes (policy packager agents) is dependent on their performance scores.

Use of the Fruchterman and Reingold algorithm (1991) when large numbers of packages are under analysis helps in identifying those that are closely related to each other and share similar nodes. A look at the upper right corner of Figure 7-6 very quickly identifies two packages (6 and 9) that have identical scores (sizes) and contain the same policy measures. On the left side, packages 8, 18 and 15 are closely related; however, in this instance it is evident that package 15 has the lowest performance score. The complexity vs. performance chart corresponding to the data on Figure 7-6 is included in Appendix A.10 and illustrates the dynamics of the formulation process.

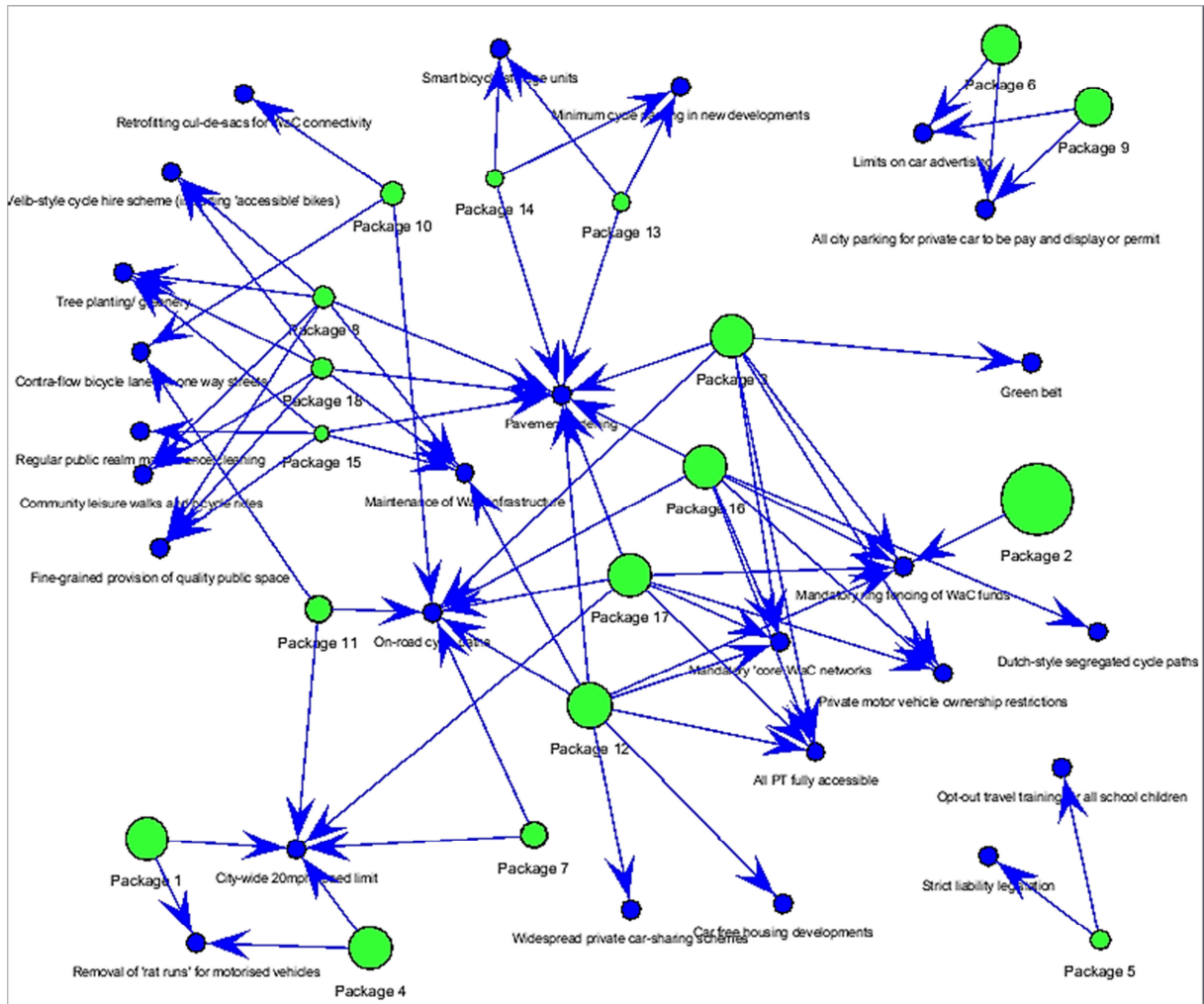


Figure 7-6 Use of the Fruchterman and Reingold algorithm and of scaling based on the policy package performances

7.3.4. User Panel and User Interaction

Additional information about individual policy packages and full details of the policy measures within and outside each package can be obtained using the custom-defined user panel. Figure 7-7 illustrates the use of the User Panel in the analysis of policy package 17 (as shown at the centre of Figure 7-6). All of the policy measures within the package are displayed and, by selecting an individual one, it is possible to probe its relations in the five pre-defined networks. Policy package 17 has seven policy

measures, and Policy Measure 35 (“Private motor vehicle ownership restrictions”) does not have any contradiction or potential contradiction relations; however, it has two preconditions, ten synergies and one facilitation. At the bottom of the User Panel, a Legend button will display the full details of any policy measure (i.e. full name, ID, properties and score) and there is also a facility to add or remove policy measures to/from policy packages manually.

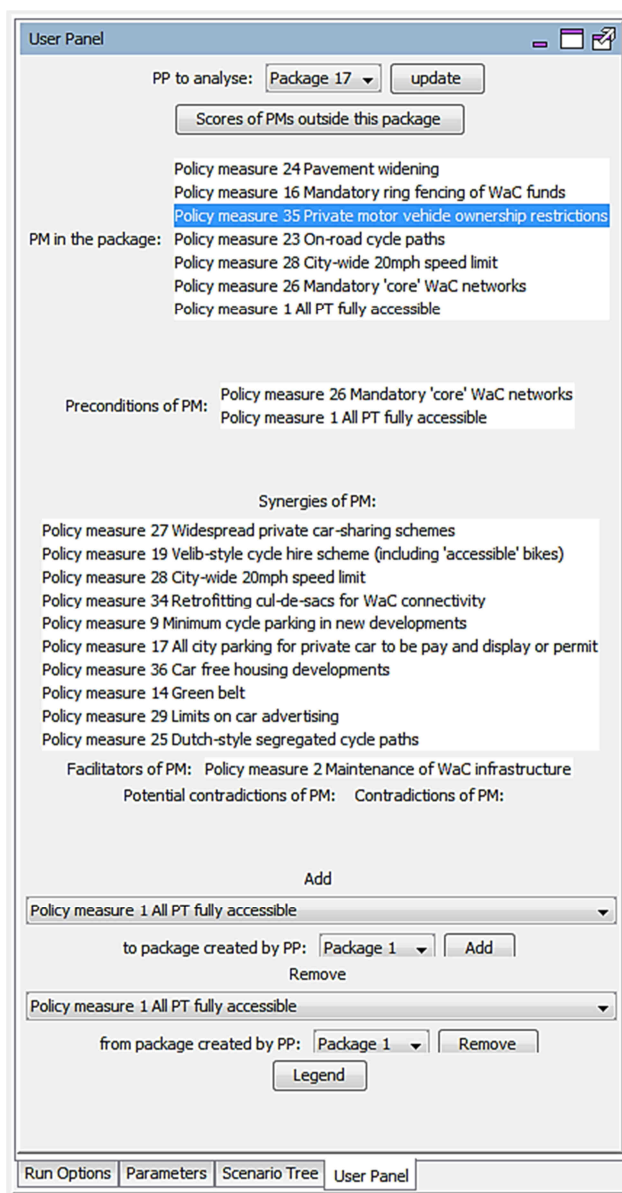
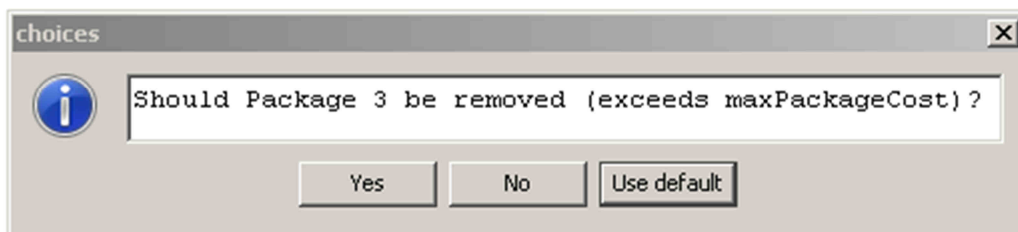
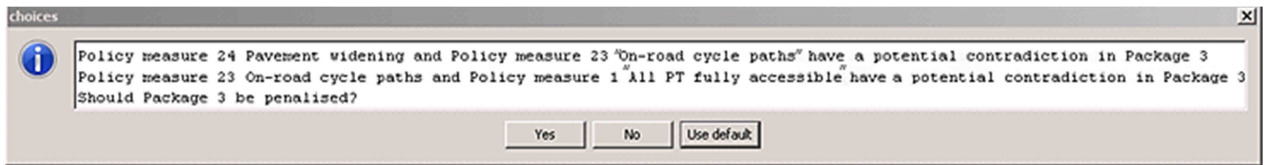


Figure 7-7 Package analysis and manipulation in the User Panel

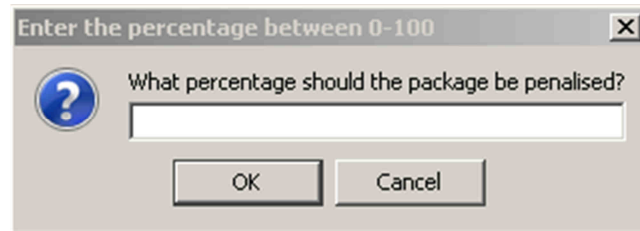
As illustrated in Figure 6-6, at different stages of each iteration step Policy Packer agents perform a set of operations to check the viability of the policy packages they have created. These examinations include checking their cost, time required for implementation and the existence of contradictions or potential contradictions. In the default mode, the Policy Packer agents perform some actions based on global parameters provided by the user. These actions may include notifying the user, rejecting the addition of a policy measure to a package or penalizing the score of a policy package. Under the interactive mode, the system relies on the user's judgement for performing these critical steps. For instance, if the maximum cost allowed in a package is exceeded, this will result in dialogue (a) in Figure 7-8 being presented to the user. If contradictions exist within the core of a package (top policy measure and its free of preconditions), the package will be deactivated. In the case of the interactive mode, a message similar to that seen in Figure 7-8 (a) is presented to the user, who can then decide whether to keep the package or deactivate it. In cases where contradiction appears due to the addition of new policy measures (not within the core of the package), the system can skip those policy measures or seek expert judgement (depending on whether the default or the interactive mode has been selected). In all the cases when potential contradictions arise within the package, the score of the packages can be penalized by a default percentage based on the number of potential contradictions or, in the interactive mode, based on user input as shown in figures 7-8 (b) and (c).



(a)



(b)



(c)

Figure 7-8 (a) Notification of a policy package exceeding the maximum allowed package cost (b) Notification when potential contradictions exist in the package (c) User input for package penalisation

7.3.5. Real-time Feedback and Design Exploration

In order to explore certain aspects of a formulated policy in traditional policy-making, the relevant information can often be obtained only after a long period of time and by investment of significant effort. We need to significantly reduce the time and effort required for such analyses, which in turn will allow exploring a larger portion of the design space and thus improve understanding of the effects of the choices at a finer granularity. The disconnect between various aspects and phases of analyses has to be resolved, as it is important to see the effect of the changes not only on the immediate issues they affect but also on the overall system. With such facilities, experts can gain immediate feedback and visual cues when changes are made and they can better understand the effects of their decisions with minimal effort, which in turn will further encourage the carrying out more detailed analyses.

The agent-based system can assist experts in exploring different aspects of the packages or policy measures and provides them real-time feedback. The system can support changes to the properties of the policy measures and/or their interactions, the manual

addition or removal of policy measures to/from different policy packages, or changes to the criteria weights assigned for the assessment of the packages during runtime. The effects of these changes can be immediately observed in the next iteration step in various charts and visualizations.

For instance, Figure 7-9 is the visualization of the policy package scores from Figure 7-1 scaled according to the default criteria weights (40% Cost, 20% Timescale of implementation and 40% Total effect). These weights can be changed during runtime. In the next iteration step after a change of weights, the Assessor agents carry out the comparison among packages, re-evaluate their package scores and various visualizations are updated. By coupling the ranking methodology, the selection algorithm and the visualization of the results, it thus becomes possible for the user to immediately observe the effects of the input parameters (in this instance criteria weights) on the system. Figure 7-10 is a visualization of the performance scores based on updated values for performance criteria weights (20% Cost; 10% Time scale of implementation and 70% Total effect). In Figure 7-9, Package 2 (which only contains one policy measure) has a similar score to package 3 (with a much larger number of policy measures). This is because a weight of 40% of the performance score is highly favourable to small packages with low costs, such as package 2. However, when cost only accounts for 20% of the score, the performance of package 2 decreases (see Figure 7-10).

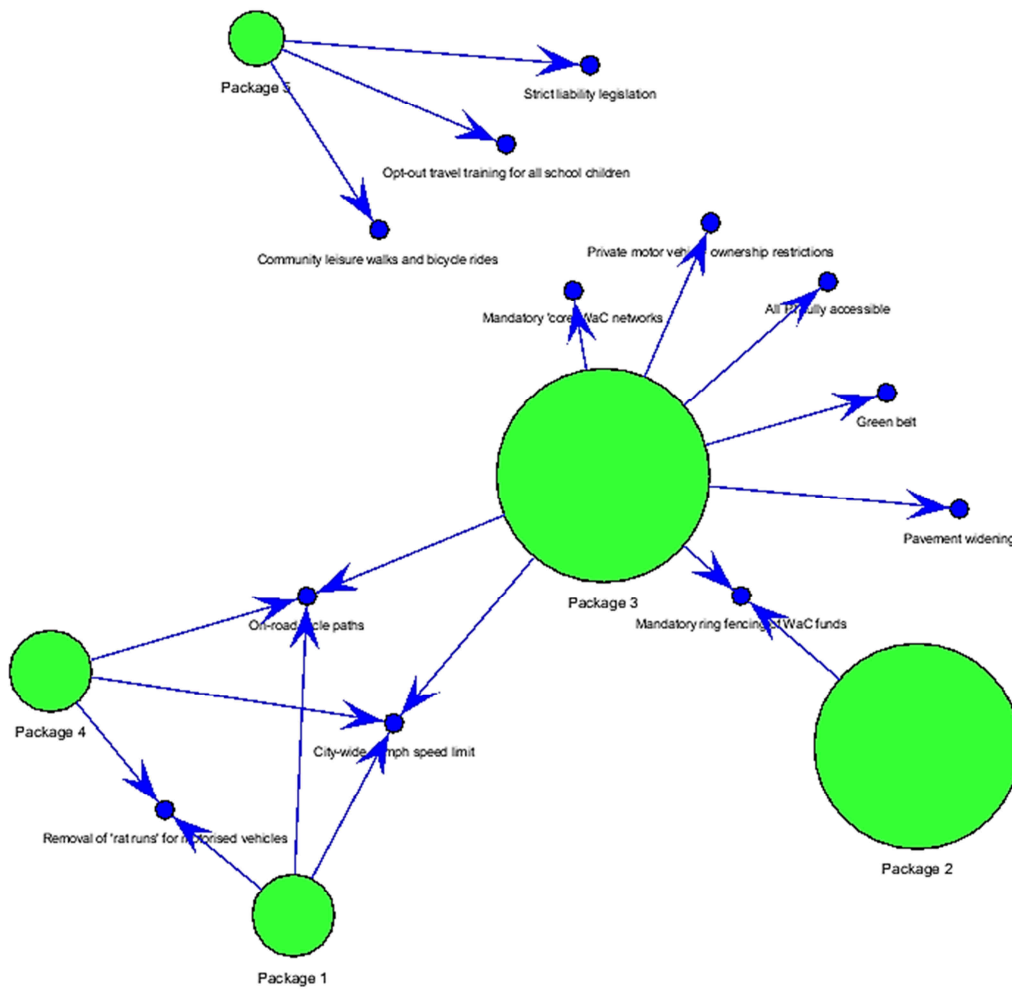


Figure 7-9 Policy packages performance scores based on default criteria weights: Cost (40%), Time scale of implementation (20%), and Total effect (40%)

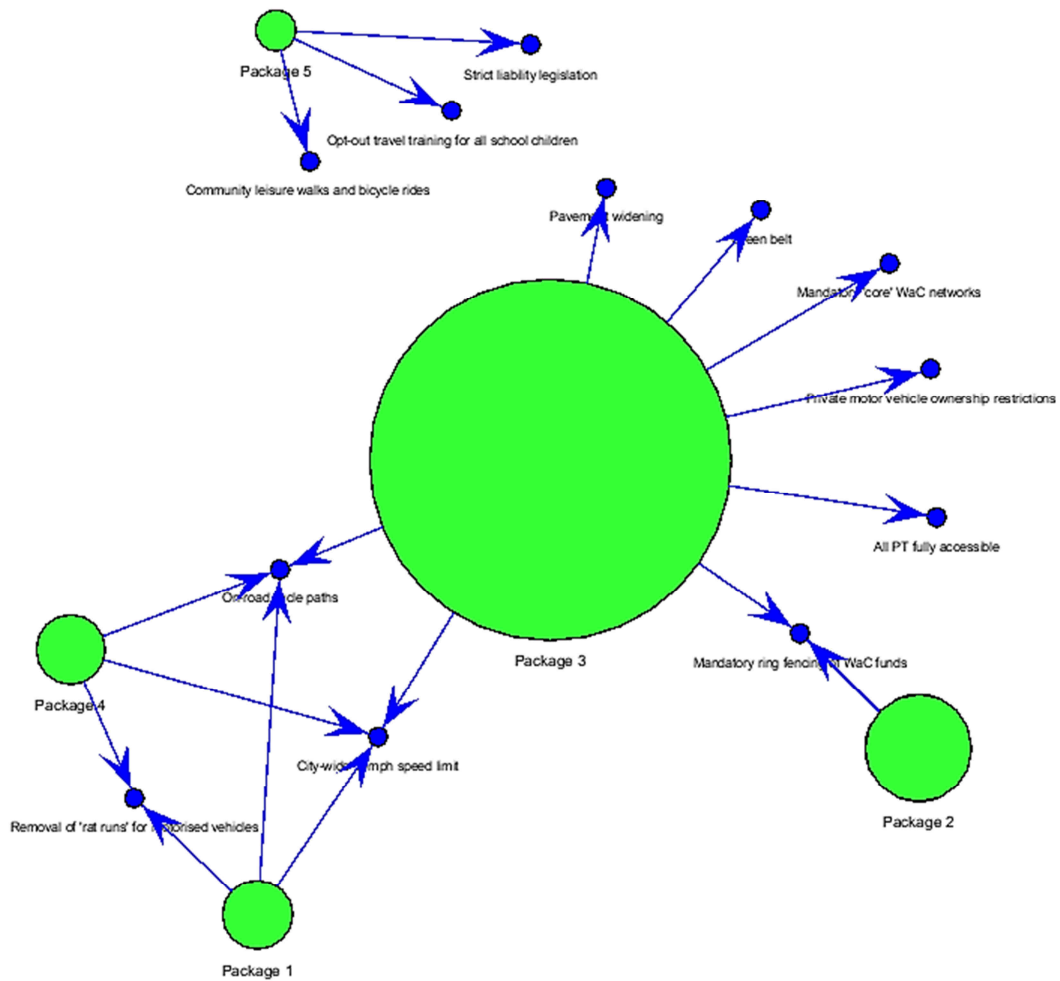


Figure 7-10 Policy packages performance scores based on modified weights: Cost (20%), Time scale of implementation (10%), Total effect (70%)

7.4. Conclusions

The complex nature of many policy problems is making the task of policy-making increasingly difficult. Our efforts are focused towards developing methodologies and support tools to improve policy design and formulation. We have explored the potential of applying an ABM system as a virtual environment for the exploration and analysis of different policy measure configurations in order to formulate and assess alternative policy packages for the promotion of walking and cycling in cities.

The agent-based approach utilizes information about the internal properties of policy measures, their interactions with each other, and of user preferences for the analysis and formulation of policies. The agent-based approach integrates techniques such as conceptual design, network analysis and MCDA, and offers an interactive mode in which agents rely on user input for a variety of decisions. The approach enhances the ability of policy-makers to systematically consider a large number of policy measures, configure and analyse different policy packages in a shorter period and at a greater depth and provides real-time feedback and a variety of visualization options to help them grasp the implications of their choices. The purpose of the research is to facilitate the design of policies and help in forming more effective, synergistic and reinforcing policies while avoiding internal contradiction. It is based on ideas that originate in engineering design and complexity science.

7.5. Summary

In this chapter, we described the approach taken in applying the methodologies described in Chapter 6 for the development of a virtual environment to build and assess policy packages for the promotion of walking and cycling in cities based on the input data gathered for the second case study (Chapter 5). The implementation details and the data used were illustrated, followed by the results from the system. The advantages of using the agent-based system in the development of policy packages (i.e. providing real-time feedback, various visualizations and charts, expanding the portion of the decision space considered, and providing user interaction) were presented. Finally, conclusions were provided.

Chapter 8

Conclusions and Future Work

8.1. Summary

8.1.1. Background and Motivation

The complex nature of many problems is making the task of policy-making increasingly difficult and requires the development of new methods to assist policy-makers in making choices and decisions. There is a consensus among experts that due to these complexities, most policy problems can only be appropriately dealt with through a range of different policy measures (i.e. a policy package). However, this requires the consideration and assessment of numerous options for policy action and the processing of a vast amount of relevant information in order to make an informed decision. The use of computational approaches is essential to consider a larger portion of the decision space and to fully utilize the knowledge and experience of policy-makers.

8.1.2. Goals of the Research

The purpose of this research is to facilitate the design and formulation of policies by developing methodologies and support tools. This is done by using knowledge gained in other fields that address design issues in a similar way to policy design. In particular, our ideas originate in engineering design and complexity science and our focus has been especially directed towards the similarities between process and policy design with the specific aim of introducing a new framework and systematic thinking to the problem of policy formulation. The purpose of these approaches is to accelerate the task of policy-making and to help in forming more effective, synergistic and reinforcing policies while avoiding internal contradictions.

8.1.3. Deliverables and Contributions

A six-step framework (Chapter 3) and a set of methodologies based upon it (Chapter 4) that allow a systematic approach to the synthesis and configuration of policies have been implemented in two case studies (Chapter 5). They have then been used for development of a DSS that aids in the development of policies (Chapter 6) and an example of its implementation (Chapter 7). The methodologies developed for the analysis and ranking of policy measures for the formulation of policy packages were applied to two case studies aiming to reduce emissions from the UK transport sector and to promote walking and cycling in cities.

An innovative aspect of the research is the definition and classification of five types of relations between policy measures (precondition, facilitation, synergy, potential contradiction and contradiction) and their application when selecting measures for implementation. Using libraries of policy measures in the two case studies, we explored these relations among policy measures and five networks of policy measure relations were created in each case, with policy measures as nodes and their interactions as the edges.

A policy measure ranking and assessment methodology was developed to enable quantitative comparison of the policy measures and to assist in their analysis and selection for implementation by relying on the application of network theory and MCDA approaches. Moreover, network visualizations were carried out to help the experts in better grasping the interactions among policy measures. The visualizations allow gleaning a large amount of vital information from the policy measure networks, which might have been overlooked otherwise simply due to the difficulty in grasping the multiple links between policy measures.

Overall, the analysis in both case studies suggests the framework and the methodologies are useful in dealing with a large number of policy measures (123 in the first case and 38 in the second), which already represent a much larger portion of the decision space than would otherwise be considered. The methodologies allow policy-makers to systematically consider a large number of measures in dealing with a specific policy objective and take into account additional information (e.g. relations between measures and implementation attributes), going beyond that traditionally considered while also simplifying the analysis through visualization and ranking. Consequently, this allows policy makers to gain a better understanding of the potential effectiveness and implementation complexity of each measure, on its own and when considered together with other measures within a policy package.

Furthermore, a unique working prototype DSS has been developed. We have explored the potential of applying an ABM system as a virtual environment for the exploration and analysis of different policy measure configurations in order to formulate and assess alternative policy packages. We have applied it to the case of the promotion of walking and cycling in cities. The agent-based approach utilizes information about the internal properties of policy measures, their interactions with each other, and user preferences

for the analysis and formulation of policies. It integrates techniques and methodologies developed for the analysis and ranking of policy measures and offers an interactive mode in which agents rely on user input for a variety of decisions.

Considering the vast amount of information available and recognizing the high level of complexity in the policy measure networks, the prototype DSS further enhances the ability of policy-makers to systematically consider the large number of policy measures, configure and analyse different policy packages in a shorter period and in greater depth and provides real-time feedback and a variety of visualization options to help them grasp the implications of their choices. Furthermore, a trend in decentralization is apparent in the medical field with the introduction of tailor-made diagnosis and treatment solutions, in the energy sector through the introduction of small-scaled decentralised power generation units, and in the policy realm by empowering the city councils and local authorities in decision-making. Use of DSS systems can help decentralised decision-making.

Overall, these methodologies and the support tool can increase understanding of the analysis and its results and thus the level of ‘knowledge utilization’ in the policy process (Landry et al., 2001). The proposed methods and the computer implementation are fundamentally different from the tools commonly used in the transport sector specifically and in policy-making in general. As such, they complement (not substitute nor compete with) existing mathematical modelling tools. The methodologies and tools are intended to support policy-makers. These experts are still needed to ‘bring together’ the understanding gained from considering separately each of the networks and combining this with information on the characteristics of each measure, experimenting with and analysing different configurations of these policy measures. It should be emphasised again that the DSS described in this thesis is intended for the generation of

different alternatives and their initial screening and not for their evaluation (e.g. via simulation).

We believe that the development of tools that allow the quantitative assessment of policy merits is a significant step towards a more systematic approach to policy formulation. The results have the potential to accelerate and significantly improve the design of policies through the use of a computational methodology. In so doing, they clearly improve a policy's chances of success.

The contributions of the thesis (with transport as the case study) are:

a) A fresh contribution to the methodological development of policies and demonstration of the usefulness of computational approaches in addressing the complexity inherent in the formulation of policies.

b) Development of a new framework for policy formulation which has the potential to:

(i) Accelerate the design of new policies and the updating of existing ones;

(ii) Improve the chances of policy success through the exploration of more alternatives for target achievement through the generation, representation and evaluation of alternatives and support to the evolutionary nature of the design by incremental operation; and

(iii) Facilitate the specialized development of transport policies for different regions and points in time and provide support in the integration of different systems, tools and information for decision-making.

(c) Application and integration of network analysis techniques for improved visualization and ranking of policy measures in the policy formulation process.

(d) Development of a more holistic approach to improve the quantitative assessment of the merits of policy measures and packages, thus considering not only their internal properties but also their interactions.

(e) Development of a novel ABM approach for the formulation of policies that:

- (i) integrates the results from network analysis and policy ranking;
- (ii) provides a virtual environment for the exploration and analysis of different configurations of policy measures in order to build policy packages; and
- (iii) tests the effects of changes and uncertainties while formulating policies.

8.1.4. Scope and Limitations

There are three possible bases for comparing the results of a model during its validation: (1) with respect to the real system; (2) with respect to the results of another model; and (3) with respect to what would be expected by the experts in the specific field (North and Macal, 2007). With regard to policy formulation and design, it is not possible to compare the results with respect to the real system, as this would require the implementation of the policies beforehand. For instance, in the study undertaken, which deals with promotion of walking and cycling by the year 2030, this would imply waiting for two decades to compare the predicted results from the DSS with a real system implementation. As this work is first of its kind, other methods and models cannot be used for its validation. Therefore, in this thesis, we validated the results by seeking expert opinion from transport policy experts. This is in line with the survey by Heath et al. (2009) that shows 95% of agent-based modelling approaches employ expert opinion as the primary form of validation.

The first case study was carried out initially to explore some of our ideas using the data from the VIBAT project (Banister and Hickman, 2006b). While carrying out the study, the results were shared with the experts at the Transport Studies Unit of the Oxford University Centre for the Environment. The experts agreed with the approach taken in the development of the policy formulation framework and the methodologies based upon it at the time and realised there were aspects of the policy measures which they had not thought about or considered before using the methodologies. In particular the simplicity of the ranking approach while taking into account various aspects of policy

measures that traditionally were neglected, the power of the visualisations and different visual cues in helping the experts in identifying patterns, gaps, outliers and clusters, and the advantages of the decision aid tool were appreciated. This resulted in a close collaboration with the Transport Studies Unit and the carrying out of the second case study on the promotion of walking and cycling, as well as adoption of the approaches in the ongoing OPTIC (2010) and Visions (Tight et al., 2011) EU and UK projects. During a period of more than two years, the methodologies and the support system were validated by experts involved in these projects and the results were verified. Furthermore, alongside numerous presentations and publications, a number of workshops were conducted to gain feedback from other experts and further validate the work (see Section 1.4).

We believe that this research constitutes the first step towards the development of a general family of computer-based systems that support the design of policies. The framework, methodologies, and decision aid tool are based on the analysts' expertise and have been successfully applied to the transport sector. The results demonstrate the use of computational approaches in addressing the complexities inherent in the formulation of policies. We believe these approaches are generic in nature and are applicable to different domains (transport, energy, food, health, water, etc.) aiming to achieve environmental, security, health or safety targets for different policy circumstances (international, regional, national, municipal, etc.). It is worth emphasising that as Banares-Alcantara (2010) points out, we should not be under the illusion that these approaches can always be accurate or complete due to the intrinsically unpredictable nature of some of the systems. However, even in such systems these approaches can be useful as they can help us in better grasping the complexities involved.

The development of the framework, methodologies and decision aid tool has a number of limitations. These include:

1. Policy measure assessment and ranking:

Assessment and ranking of the policy measure and packages was done by MCDA using a weighted summation of the scores; this method can be enhanced.

2. Policy measure network:

The policy measure networks analysed in this thesis are not weighted, which means that all relations are equal. By switching to weighted networks the importance of the relations among policy measures can be better differentiated.

3. Policy measures:

We only considered policy measures that directly affect the policy goals (primary measures). However considering non-primary policy measures can also be beneficial, e.g. if they support the implementation of primary-measures.

4. Goals:

Currently only a single type of a goal is considered in this research. Consideration of multiple goals and the trade-offs between them can enhance this work.

5. Stakeholders:

Currently we assume that the data provided to the system is based on consensus (which has been the case in the case studies). However, in cases where such consensus cannot be reached having the ability to consider multiple stakeholders would be beneficial.

8.2. Future Work

The work presented in this thesis has introduced a number of original ideas that can be enhanced and expanded in further research. The main avenues to explore to improve this research are:

1. Policy measure assessment and ranking:

In this study, MCDA was carried out by summation of the scores, as the focus of this thesis was on the development of the methodology for the assessment of policy measures. More suitable MCDA techniques could be identified and adopted.

2. Switch to a weighted network:

In this thesis, the relations between policy measures (edges) are not weighted. A switch to a weighted network would result in differentiation of the level in which measures relate to each other, thus better capturing the real-life interactions among the measures. However, the extent to which a relationship can be quantified, e.g. the degree to which facilitation can increase effectiveness, is questionable. That said, if models exist that could provide estimations of the effects (e.g. how much measure X is likely to facilitate measure Y), such information should be considered in the analysis.

3. More detailed network analysis:

The community structure analysis has resulted in observations that could improve the understanding of domain experts during the design and formulation of policies. The area of network analysis is rapidly advancing and attempts should be made to utilize its latest advancements. Future work should try to incorporate in the algorithm the internal properties of the policy measures in addition to their structural interactions. Furthermore, several other network features, such as robustness, eccentricity and graph

colouring, can also be investigated for potential use in the refinement and evaluation of policy alternatives.

4. Integration with GIS:

At present, the extent to which a policy measure is implemented (for example, the size of the area covered by a new bicycle hire scheme) is not accounted for, although it will of course affect the implementation complexity and level of effectiveness.

5. Consideration of non-primary measures:

The methodologies developed only deal with the primary policy measures. The non-primary policy measures (measures that are not expected to directly affect the policy objectives, but are expected or anticipated to increase the efficiency and success of a policy package by facilitating its implementation) can also be included in future analyses. Such measures can have positive effects by reducing unintended effects and/or increasing their level of acceptability.

Furthermore, the generation and evaluation procedures of the ABM system could be improved by considering:

6. Temporal analysis:

Detailed consideration of the temporal aspects of policies has not been the focus of this thesis. It is important to address the temporal elements and consider the effects of a failure or a delay in the implementation of a measure, replacement of a measure with a new measure with different characteristics, or failure to take account of the risks and uncertainties that could affect the policies. The effect of such occurrences could be analysed on other policy measures and on the overall policy. As a result, the robustness of the envisaged alternatives with regards to such occurrences can then be examined.

7. Multiple goals:

The current prototype only considers a single type of a goal relating to the promotion of walking and cycling. Exploring multiple competing goals and considering their effect on the ranking and development of policies is important, as in such a case policy measures might contribute to or adversely affect different objectives in a different fashion. The goals may be formally defined using a method similar to the one proposed by Hashmi et al. (2003), where each goal has a number of properties such as a reduction target, a desired time frame for implementation, a level of priority, and a context for the actions. The system will examine policy measures and will try to match them with the properties of the goals. Furthermore, the priority of the goals will be utilized in the evaluation of policy alternatives.

8. Consideration of multiple stakeholders:

Currently, we assume that their differences are resolved before the data is provided to the system. The development of a methodology that considers multiple stakeholder involvement in the policy formulation process is desirable. Furthermore, future DSSs could be enhanced so that they could be used for involving non-specialist users, in particular the people that get directly affected by the policies.

9. Exploring the possibility of integrating the system with evaluation models:

This can be achieved by finding suitable simulation models and feeding them the results from the system, running them to see the effects of the proposed alternatives. The process can be carried out to find out the trade-offs of different policies, using external systems alongside the internally developed assessment techniques.

10. Exploring the use of ontologies:

An ontology is a formal, machine-readable and explicit representation of knowledge about a domain in terms of concepts (classes and instances) and different types of

relationships among them, resulting in a richly interconnected network structure. In simplistic terms, ontologies can be seen as extensions of the object-oriented representation. The use of ontologies (Uschold and Gruninger, 1996) is advantageous for the DSS due to features such as the ability to represent concepts, their properties, and their relations. Moreover, the possibility of using abstraction and scaling on the ontology because of the existence of hierarchies is a further advantage. Transition from databases can be achieved by the development of ontologies for the domains of transport policy and environmental targets, for instance in the case studies in this thesis.

Appendix

A.1 MCS Code for Sensitivity Analyses

MCS runs for sensitivity analysis to input data were performed by changing the number of matrix manipulations and number of simulation runs in different scenarios in Section 5.2.5 by using the following Visual Basic Macro code:

```
Sub MCSAnalysis()  
  
    'number of matrix manipulations  
    changes = 159  
  
    'number of simulation runs  
    numberRuns = 1000  
  
    'in each iteration randomize the matrix, obtain and store 'the results  
    due to changes  
    For m = 1 To numberRuns  
  
        'clear matrix  
        Sheets("Overall").Select  
        Range("D4:DV126").Select  
        Selection.ClearContents  
  
        'update cleared matrix based on the data  
        Sheets("Backup").Select  
        Range("D4:DV126").Select  
        Selection.Copy  
        Sheets("Overall").Select  
        Range("D4").Select  
        Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone,  
        SkipBlanks _  
            :=False, Transpose:=False  
  
        'create random numbers for randomizing the matrix  
        For n = 1 To changes  
            i = Round(123 * Rnd + 1) + 3  
            j = Round(123 * Rnd + 1) + 3  
  
            k = Rnd
```

```

'randomize the matrix
Sheets("Overall").Select
If Cells(i, j) <> "0" Then
Cells(i, j).Value = "0"
'MsgBox "Removed now is empty!"
ElseIf k < 0.1499051233 Then
Cells(i, j).Value = "P"
'MsgBox "Added P"
ElseIf k >= 0.1499051233 And k < 0.89943074 Then
Cells(i, j).Value = "F"
'MsgBox "Added F"
ElseIf k >= 0.89943074 And k < 0.9658444023 Then
Cells(i, j).Value = "S"
'MsgBox "Added S"
ElseIf k >= 0.9658444023 And k < 0.9990512334 Then
Cells(i, j).Value = "PC"
'MsgBox "Added PC"
ElseIf k >= 0.9990512334 Then
Cells(i, j).Value = "C"
'MsgBox "Added C"
End If

'store the results from randomizing the matrix
Next
Sheets("Index-Combined").Select
Range("AA5").Select
Selection.Copy
Cells(4 + m, 30).Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone,
SkipBlanks _
:=False, Transpose:=False
Cells(4 + m, 29).Value = m

Range("AB5").Select
Selection.Copy
Cells(4 + m, 33).Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone,
SkipBlanks _
:=False, Transpose:=False
Cells(4 + m, 32).Value = m

Next

End Sub

```

A.2 Assessment of Policy Measures in the First Case Study

The details of the assessment of the policy measures in the first case study are presented. The first case study's Excel workbook sheets are well above 100 pages long if printed. Therefore, the actual files with the policy measure relations adjacency matrix, various decompositions based on the matrix, etc. are available on the internet addresses provided in Appendix A.9 along with ABM model.

PM ID	Policy Measure	PM Basic Data			Index Based on Preconditions								
		Effectiveness	Timescale of implementation	Cost	nom-P-in	nom-P-out	nom-Betwms	Utility Value of Cost	Utility Value of Efficiency	Utility Value of Time	Network Score	Primary Score	Combined Indx
1	Standards for emissions, noise and safety	3	2	1	0.0443	0.0081	0.0607	0.0053	0.0118	0.0039	0.0331	0.0076	0.0127
2	Fuel quality standards	3	2	1	0.0380	0.0082	0.0000	0.0159	0.0118	0.0097	0.0185	0.0130	0.0141
3	Alternative fuel research and development	3	2	2	0.0000	0.0082	0.0000	0.0080	0.0118	0.0097	0.0033	0.0098	0.0085
4	Efficiency improvement of materials and energy (e.g. factor 4)	2	2	1	0.0000	0.0082	0.0000	0.0159	0.0079	0.0097	0.0033	0.0114	0.0068
5	Dematerialisation of products and miniaturisation	3	2	1	0.0000	0.0082	0.0000	0.0159	0.0118	0.0097	0.0033	0.0130	0.0111
6	Vehicle test cycles	1	2	1	0.0127	0.0081	0.0022	0.0080	0.0039	0.0048	0.0088	0.0057	0.0063
7	Enforcement and monitoring	2	2	1	0.0898	0.0082	0.0000	0.0159	0.0079	0.0097	0.0387	0.0114	0.0169
8	Improvement of public transport - bus, guided bus, etc.	3	2	2	0.0063	0.0081	0.0217	0.0032	0.0118	0.0039	0.0101	0.0088	0.0074
9	Increased rail capacity and high speed trains (HST)	3	3	1	0.0000	0.0081	0.0000	0.0053	0.0118	0.0039	0.0033	0.0076	0.0067
10	Public transport subsidy (investment)	3	2	2	0.0316	0.0082	0.0000	0.0080	0.0118	0.0097	0.0159	0.0098	0.0111
11	Deregulation	2	2	1	0.0000	0.0082	0.0000	0.0159	0.0079	0.0097	0.0033	0.0114	0.0068
12	Fare integration and schedule co-ordination	1	2	2	0.0000	0.0081	0.0000	0.0053	0.0039	0.0065	0.0033	0.0050	0.0046
13	Intermodality	1	2	2	0.0000	0.0081	0.0000	0.0040	0.0039	0.0039	0.0032	0.0039	0.0038
14	Traveller information	1	1	1	0.0127	0.0082	0.0000	0.0159	0.0039	0.0194	0.0083	0.0118	0.0111
15	Bus service improvement	1	1	2	0.0000	0.0081	0.0000	0.0027	0.0039	0.0039	0.0032	0.0034	0.0034
16	Park and ride	3	1	2	0.0000	0.0081	0.0000	0.0032	0.0118	0.0048	0.0032	0.0070	0.0062
17	Rail freight facilities	1	1	1	0.0000	0.0082	0.0000	0.0159	0.0039	0.0194	0.0033	0.0118	0.0101
18	Walking and cycle facilities	1	1	2	0.0316	0.0080	0.0716	0.0032	0.0039	0.0048	0.0302	0.0038	0.0091
19	Cycle/public transport integration	1	1	2	0.0000	0.0081	0.0000	0.0040	0.0039	0.0065	0.0032	0.0045	0.0042
20	Cycle parking	1	1	1	0.0316	0.0081	0.0065	0.0080	0.0039	0.0097	0.0172	0.0067	0.0088
21	Shuttle services	2	1	1	0.0000	0.0082	0.0000	0.0159	0.0079	0.0194	0.0033	0.0134	0.0114
22	Small wheeled public transport/paratransit	2	2	2	0.0000	0.0082	0.0000	0.0080	0.0079	0.0097	0.0033	0.0083	0.0073
23	Demand responsive services	2	2	1	0.0000	0.0078	0.0000	0.0023	0.0079	0.0018	0.0031	0.0044	0.0042
24	Taxi services	1	1	1	0.0000	0.0082	0.0000	0.0159	0.0039	0.0194	0.0033	0.0118	0.0101
25	Teleworking/telecommuting/teleconferencing	1	2	2	0.0263	0.0081	0.0195	0.0032	0.0039	0.0032	0.0173	0.0035	0.0062
26	Teleshopping/teleshopping/teleshopping	1	2	2	0.0127	0.0081	0.0065	0.0032	0.0039	0.0032	0.0066	0.0035	0.0047
27	Telematics, informatics available locally	2	2	2	0.0000	0.0082	0.0000	0.0080	0.0079	0.0097	0.0033	0.0083	0.0073
28	Infrastructure technology	2	2	2	0.0000	0.0082	0.0000	0.0080	0.0079	0.0097	0.0033	0.0083	0.0073
29	Multipurpose personal communications	1	2	1	0.0127	0.0082	0.0000	0.0159	0.0039	0.0097	0.0083	0.0099	0.0096
30	Broadband, Wi-Fi, smartdust and other technological development	1	2	2	0.0190	0.0082	0.0000	0.0080	0.0039	0.0097	0.0109	0.0067	0.0075
31	Integrated planning	2	1	1	0.0443	0.0082	0.0000	0.0159	0.0079	0.0194	0.0210	0.0134	0.0149
32	Regional development policies, strategic planning	3	2	2	0.0570	0.0082	0.0000	0.0080	0.0118	0.0097	0.0261	0.0098	0.0131
33	Compact cities	3	2	2	0.0000	0.0077	0.0000	0.0011	0.0118	0.0011	0.0031	0.0054	0.0049
34	Decentralised concentration and polycentricity	3	2	2	0.0127	0.0080	0.0043	0.0020	0.0118	0.0019	0.0061	0.0059	0.0066
35	Mixed use	2	2	2	0.0000	0.0082	0.0000	0.0080	0.0079	0.0097	0.0033	0.0083	0.0073
36	Zoning regulations	2	2	1	0.0263	0.0081	0.0260	0.0040	0.0079	0.0032	0.0186	0.0054	0.0060
37	Public transport orientated development (PTOD)	3	2	2	0.0127	0.0082	0.0000	0.0080	0.0118	0.0097	0.0083	0.0098	0.0096
38	Smart growth	2	2	1	0.0000	0.0081	0.0000	0.0040	0.0079	0.0032	0.0032	0.0054	0.0050
39	New urbanism	2	2	1	0.0000	0.0077	0.0000	0.0011	0.0079	0.0010	0.0031	0.0038	0.0037
40	Clustered land use/location efficient development	2	2	1	0.0316	0.0081	0.0000	0.0053	0.0079	0.0048	0.0159	0.0062	0.0082
41	Access to transport services	2	1	2	0.0000	0.0082	0.0000	0.0080	0.0079	0.0194	0.0033	0.0102	0.0088
42	Pedestrianisation	2	1	2	0.0063	0.0081	0.1301	0.0040	0.0079	0.0065	0.0318	0.0080	0.0112
43	Commute trip reduction programmes	2	1	1	0.0000	0.0081	0.0000	0.0053	0.0079	0.0032	0.0032	0.0059	0.0054
44	School travel planning	2	1	1	0.0000	0.0082	0.0000	0.0159	0.0079	0.0194	0.0033	0.0134	0.0114
45	Special event management	2	2	1	0.0063	0.0082	0.0000	0.0159	0.0079	0.0097	0.0058	0.0114	0.0103
46	Car free planning	2	2	1	0.0263	0.0082	0.0000	0.0159	0.0079	0.0097	0.0134	0.0114	0.0118
47	Campus management	1	1	1	0.0000	0.0080	0.0000	0.0032	0.0039	0.0048	0.0032	0.0038	0.0037
48	Car clubs	2	2	1	0.0000	0.0082	0.0000	0.0159	0.0079	0.0097	0.0033	0.0114	0.0068
49	Commuter planning	2	2	1	0.0127	0.0082	0.0000	0.0159	0.0079	0.0097	0.0083	0.0114	0.0108
50	Eco labelling of vehicles	3	1	1	0.0063	0.0080	0.0043	0.0040	0.0118	0.0028	0.0066	0.0069	0.0068
51	Commuter financial incentives	2	2	2	0.0000	0.0081	0.0000	0.0040	0.0079	0.0039	0.0032	0.0055	0.0051
52	Parking cashouts	2	1	2	0.0000	0.0080	0.0000	0.0032	0.0079	0.0048	0.0032	0.0054	0.0050
53	TDM marketing	2	2	2	0.0000	0.0082	0.0000	0.0080	0.0079	0.0097	0.0033	0.0083	0.0073
54	Changed activity patterns - commuting, retail and/or leisure trips	2	3	1	0.0127	0.0082	0.0000	0.0159	0.0079	0.0065	0.0083	0.0108	0.0103
55	Alternative work schedules	2	3	1	0.0063	0.0081	0.0022	0.0053	0.0079	0.0028	0.0062	0.0058	0.0059
56	Changing lifestyles - e.g. not travelling at weekends	2	3	1	0.0000	0.0081	0.0000	0.0053	0.0079	0.0039	0.0033	0.0080	0.0055
57	Home location	2	3	2	0.0000	0.0081	0.0000	0.0040	0.0079	0.0032	0.0033	0.0054	0.0050
58	Job location	2	3	2	0.0000	0.0081	0.0000	0.0040	0.0079	0.0039	0.0033	0.0055	0.0051
59	Career downsizing	2	3	1	0.0000	0.0081	0.0000	0.0053	0.0079	0.0039	0.0033	0.0080	0.0055
60	Promotion of local destinations and local activity patterns	2	3	1	0.0000	0.0082	0.0000	0.0159	0.0079	0.0065	0.0033	0.0108	0.0093
61	Locally sourced retailing	2	2	1	0.0000	0.0082	0.0000	0.0159	0.0079	0.0097	0.0033	0.0114	0.0098
62	Car sharing	3	2	1	0.0000	0.0082	0.0000	0.0159	0.0118	0.0097	0.0033	0.0130	0.0111
63	Flexitime	2	1	1	0.0063	0.0081	0.0065	0.0040	0.0079	0.0032	0.0071	0.0054	0.0057
64	Guaranteed ride home	2	1	1	0.0000	0.0082	0.0000	0.0159	0.0079	0.0194	0.0033	0.0134	0.0114
65	Teleworking and teleshopping	2	2	1	0.0000	0.0081	0.0000	0.0032	0.0079	0.0032	0.0032	0.0051	0.0047
66	Logistics management	3	2	2	0.0000	0.0082	0.0000	0.0080	0.0118	0.0097	0.0033	0.0098	0.0085
67	Increased load factors	3	2	1	0.0000	0.0082	0.0000	0.0159	0.0118	0.0097	0.0033	0.0130	0.0111
68	Home delivery of goods/services	3	1	1	0.0000	0.0082	0.0000	0.0159	0.0118	0.0194	0.0033	0.0150	0.0128

69	Freight distribution - centralised/decentralised centres	3	2	2	0.0063	0.0082	0.0000	0.0080	0.0118	0.0097	0.0058	0.0098	0.0090
70	Locally sourced distribution chains	2	2	2	0.0000	0.0081	0.0000	0.0040	0.0079	0.0049	0.0033	0.0057	0.0052
71	Ecological tax reform	3	2	1	0.0443	0.0081	0.0271	0.0053	0.0118	0.0032	0.0284	0.0075	0.0113
72	Tradable mobility credits	3	3	1	0.0000	0.0082	0.0000	0.0159	0.0118	0.0065	0.0033	0.0124	0.0106
73	Carbon rations/domestic tradable quotas (DTQs)	3	3	2	0.0000	0.0082	0.0000	0.0080	0.0118	0.0065	0.0033	0.0092	0.0080
74	Carbon tax	3	1	2	0.0000	0.0081	0.0000	0.0053	0.0118	0.0065	0.0033	0.0081	0.0072
75	Taxes and feebates based on fuel consumption and weight	3	1	1	0.0063	0.0079	0.0098	0.0027	0.0118	0.0019	0.0078	0.0082	0.0085
76	Vehicle scrappage bonuses and tax increases	3	1	1	0.0000	0.0081	0.0000	0.0080	0.0118	0.0065	0.0033	0.0092	0.0080
77	Decentralisation of health and social services	3	3	2	0.0190	0.0080	0.0065	0.0018	0.0118	0.0018	0.0121	0.0058	0.0070
78	Decentralisation of education facilities	3	3	2	0.0190	0.0080	0.0065	0.0018	0.0118	0.0018	0.0121	0.0058	0.0070
79	Car free district	2	2	2	0.0000	0.0078	0.0000	0.0018	0.0079	0.0018	0.0031	0.0042	0.0040
80	Car free or low car housing	2	2	2	0.0000	0.0081	0.0000	0.0040	0.0079	0.0032	0.0032	0.0054	0.0050
81	Low emission zones	3	1	1	0.0063	0.0077	0.0304	0.0016	0.0118	0.0012	0.0117	0.0056	0.0068
82	Pedestrian and cycle friendly developments	1	1	1	0.0316	0.0081	0.1171	0.0053	0.0039	0.0067	0.0393	0.0056	0.0124
83	Fiscal incentives for relocation in designated areas	2	2	2	0.0000	0.0082	0.0000	0.0080	0.0079	0.0067	0.0033	0.0083	0.0073
84	Relocation of activities	2	2	2	0.0253	0.0082	0.0000	0.0080	0.0079	0.0067	0.0134	0.0083	0.0063
85	Development restrictions and green belts	3	2	1	0.0000	0.0082	0.0000	0.0159	0.0118	0.0067	0.0033	0.0130	0.0111
86	Regeneration of decaying areas (city centre, inner city, waterfront, suburban)	1	3	1	0.0000	0.0081	0.0000	0.0053	0.0039	0.0039	0.0033	0.0045	0.0042
87	Housing renewal, improvements to neighbourhood quality and facilities	2	3	2	0.0127	0.0082	0.0000	0.0080	0.0079	0.0065	0.0083	0.0076	0.0078
88	Car and cycle parking standards for new development	2	1	1	0.0253	0.0082	0.0000	0.0159	0.0079	0.0194	0.0134	0.0134	0.0134
89	Road pricing – congestion or environmental basis	3	2	1	0.0127	0.0080	0.0195	0.0027	0.0118	0.0024	0.0122	0.0063	0.0074
90	Road tolls for freight	2	2	1	0.0000	0.0080	0.0000	0.0027	0.0079	0.0022	0.0032	0.0046	0.0043
91	High occupancy vehicle (HOV) pricing	2	2	1	0.0000	0.0082	0.0000	0.0159	0.0079	0.0067	0.0033	0.0114	0.0098
92	Fuel tax/escalators	3	1	2	0.0000	0.0081	0.0000	0.0040	0.0118	0.0039	0.0032	0.0071	0.0063
93	Vehicle purchase tax	2	1	1	0.0000	0.0081	0.0000	0.0053	0.0079	0.0039	0.0032	0.0080	0.0055
94	Car ownership tax	2	1	1	0.0000	0.0080	0.0000	0.0040	0.0079	0.0028	0.0032	0.0053	0.0040
95	Parking tariffs/pricing	2	1	1	0.0063	0.0081	0.0011	0.0053	0.0079	0.0048	0.0060	0.0062	0.0062
96	Parking restrictions/controls	3	1	1	0.0190	0.0081	0.0011	0.0080	0.0118	0.0065	0.0111	0.0092	0.0096
97	Pay as you drive vehicle insurance	2	1	1	0.0000	0.0081	0.0000	0.0040	0.0079	0.0065	0.0032	0.0080	0.0055
98	Excise tax for aircraft fuel	2	2	1	0.0000	0.0081	0.0000	0.0053	0.0079	0.0039	0.0032	0.0080	0.0055
99	Airport charges	2	1	1	0.0000	0.0082	0.0000	0.0159	0.0079	0.0194	0.0033	0.0134	0.0114
100	Air travel restrictions/rations	2	3	1	0.0000	0.0081	0.0000	0.0053	0.0079	0.0028	0.0032	0.0058	0.0053
101	Entry restrictions/access control/environmental zones	2	1	2	0.0190	0.0081	0.0807	0.0040	0.0079	0.0039	0.0230	0.0055	0.0060
102	Good traffic restraint	2	1	1	0.0000	0.0082	0.0000	0.0159	0.0079	0.0194	0.0033	0.0134	0.0114
103	Road capacity restraint	2	1	1	0.0127	0.0082	0.0000	0.0159	0.0079	0.0194	0.0083	0.0134	0.0124
104	Advanced traffic management systems	3	1	1	0.0000	0.0081	0.0000	0.0053	0.0118	0.0065	0.0033	0.0081	0.0072
105	Home zones	2	1	2	0.0000	0.0081	0.0000	0.0040	0.0079	0.0067	0.0033	0.0087	0.0080
106	Street reclaiming	1	2	2	0.0000	0.0082	0.0000	0.0080	0.0039	0.0067	0.0033	0.0087	0.0080
107	Traffic calming	1	1	2	0.0000	0.0082	0.0000	0.0080	0.0039	0.0194	0.0033	0.0088	0.0076
108	Traffic bundling	1	1	2	0.0000	0.0082	0.0000	0.0080	0.0039	0.0194	0.0033	0.0088	0.0076
109	Driver information systems	2	1	2	0.0063	0.0082	0.0000	0.0080	0.0079	0.0194	0.0058	0.0102	0.0063
110	Village/area bypasses	1	1	1	0.0000	0.0082	0.0000	0.0159	0.0039	0.0194	0.0033	0.0118	0.0101
111	Road space reallocation	2	1	2	0.0253	0.0082	0.0000	0.0080	0.0079	0.0194	0.0134	0.0102	0.0108
112	Pedestrian priority and road space	1	1	1	0.0063	0.0081	0.1410	0.0032	0.0039	0.0048	0.0340	0.0038	0.0098
113	Cycle priority and road space	1	1	1	0.0000	0.0080	0.0000	0.0027	0.0039	0.0039	0.0032	0.0034	0.0034
114	Direct routes for walking, cycling and PT relative to the car	1	2	2	0.0190	0.0078	0.1822	0.0011	0.0039	0.0018	0.0472	0.0024	0.0113
115	Priorities for bus, tram and high occupancy vehicles (HOV)	3	2	1	0.0000	0.0081	0.0000	0.0053	0.0118	0.0065	0.0033	0.0081	0.0072
116	Segregated rights of way for public transport	2	2	2	0.0000	0.0081	0.0000	0.0040	0.0079	0.0065	0.0033	0.0080	0.0055
117	Increased awareness of public transport services	1	2	1	0.0127	0.0082	0.0000	0.0159	0.0039	0.0067	0.0083	0.0099	0.0096
118	Travel information	1	1	1	0.0190	0.0082	0.0000	0.0159	0.0039	0.0194	0.0109	0.0118	0.0116
119	Transport chaining awareness	2	2	1	0.0063	0.0082	0.0000	0.0159	0.0079	0.0067	0.0058	0.0114	0.0103
120	Personalised travel planning, travel blending	2	1	1	0.0000	0.0081	0.0000	0.0080	0.0079	0.0067	0.0033	0.0083	0.0073
121	Incentives to motor industry to increase hybrid car output	3	2	2	0.0000	0.0082	0.0000	0.0080	0.0118	0.0067	0.0033	0.0098	0.0085
122	Hybrid technology research	3	3	2	0.0000	0.0082	0.0000	0.0080	0.0118	0.0065	0.0033	0.0092	0.0080
123	Casualty reduction targets (Zero objective)	1	1	1	0.0063	0.0081	0.0347	0.0053	0.0039	0.0039	0.0127	0.0045	0.0081

A.3 Policy Measure Properties in Second Case Study

The second case study's policy measure properties, relations and ranking results are presented through appendices A3-A8 and the actual Excel file is available on the internet at addresses described in Appendix A.9 along with the ABM code and other relevant files.

#	MEASURE TITLE	Measure Properties							
		Cost (C)	Effectiveness (E)	Timescale of implementation (I)	Timescale of lasting implementation effect (LT)	Time from end of implementation to effect being felt (delay) (D)	Technical complexity	Public (un)acceptability	Institutional complexity
2	All PT fully accessible	medium	Low	medium	long term	immid.	low	low	low
3	Maintenance of WaC infrastructure	High	High	medium	medium	immid.	low	low	low
6	Regular public realm maintenance/cleaning	medium	medium	short	short	med.	low	low	low
7	Widespread Sheffield stands	medium	medium	medium	long term	med.	low	low	low
8	Opt-out travel training for all school children	medium	Low	medium	long term	long	medium	low	medium
10	Fine-grained provision of quality public space	High	medium	long	long term	med.	medium	low	High
11	Raised pedestrian crossings instead of dropped kerbs	medium	low	long	long term	immid.	low	Medium/high	low
13	Tree planting/ greenery	medium	low	medium	long term	med.	low	low	medium
21	Minimum cycle parking in new developments	Low	high	short	long term	med.	low	low	medium/low
26	Freight windows	Low	Low	short	long term	immid.	medium	Medium/high	high
28	Strict liability legislation	low	Medium/high	long	long term	long	low	high	high
29	Workplace crèches	medium	low	long	long term	immid.	high	low	high
30	Flexible working hours	medium	low	long	long term	immid.	high	Medium	high
31	Green belt	low	high	long	long term	long	high	high	high
33	Smart 'oyster-style' cards for all mobility	medium	low	medium	long term	med.	high	low	medium
34	Mandatory ring fencing of WaC funds	low	high	medium	long term	long	low	low	medium
36	All city parking for private car to be pay and display or permit	low	low	medium	long term	immid.	low	medium	low
38	Removal of 'rat runs' for motorised vehicles	low	low	short	long term	immid.	low	medium	low
42	Velib-style cycle hire scheme (including 'accessible' bikes)	high	high	medium	long term	med.	medium	low	low
47	Dutch-style railway parking facilities	high	medium	medium/long	long term	med.	medium	low	medium
52	Community leisure walks and bicycle rides	low	low	short	medium	long	low	low	low
53	Walking buses to school for young children	low	medium	short	long term	long	low	low	medium
54	On-road cycle paths	medium	high	medium	long term	immid.	low	medium	low
56	Pavement widening	high	high	medium/long	long term	immid.	medium	low/medium	medium
57	Dutch-style segregated cycle paths	high	high	high	long term	immid.	high	low/medium	high
61	Mandatory 'core' WaC networks	high	High	high	long term	med.	high	low	medium
70	Widespread private car-sharing schemes	medium	low	medium	medium	med.	low	low	low
72	City-wide 20mph speed limit	low	high	medium	long term	med.	low	medium/high	low
75	Limits on car advertising	low	low/medium	short	short	long	low	low	high
78	Contra-flow bicycle lanes in one way streets	low	high	short	long term	immid.	low	medium	low
79	Public fitness campaign	medium	low/medium	short	short	med.	low	low	low
86	Smart bicycle storage units	medium/high	medium/high	medium/long	long term	immid.	medium	low	medium
87	Cycle traffic enforcement	medium	medium	short	long term	immid.	low	medium	low
94	Retrofitting cul-de-sacs for WaC connectivity	medium/high	high	medium	long term	immid.	high	medium	medium
103	Private motor vehicle ownership restrictions	low	high	short	long term	med.	high	high	high
112	Car free housing developments	low	high	high	long term	med.	low	medium	low
115	Consolidated neighbourhood goods delivery	medium	low	medium	long term	immid.	medium	low	medium
118	Orange NEV/HPV routes 20mph	high	medium	high	long term	med.	high	medium	medium

A.4 Policy Measure Relations in the Second Case Study

A.5 Traditional Performance Ranking in the Second Case Study

		Cost (C)	Effectiveness (E)	Timescale of implementation (T)	Timescale of lasting implementation effect (LT)	Time from end of implementation to effect being felt (delay) (D)	Utility value of cost	Utility value of implementation time	Utility value of length of effect	Weighted value of the individual measure
	Weight						0.4	0.2	0.4	
ID	Policy Measure									
2	All PT fully accessible	3	1	3	5	1	0.0161	0.0306	0.0093	0.0163
3	Maintenance of WaC infrastructure	5	5	3	3	1	0.0096	0.0306	0.0279	0.0211
6	Regular public realm maintenance/cleaning	3	3	1	1	3	0.0161	0.0306	0.0056	0.0148
7	Widespread Sheffield stands	3	3	3	5	3	0.0161	0.0204	0.0279	0.0217
8	Opt-out travel training for all school children	3	1	3	5	5	0.0161	0.0153	0.0093	0.0132
10	Fine-grained provision of quality public space	5	3	5	5	3	0.0096	0.0153	0.0279	0.0181
11	Raised pedestrian crossings instead of dropped kerbs	3	1	5	5	1	0.0161	0.0204	0.0093	0.0142
13	Tree planting/greenery	3	1	3	5	3	0.0161	0.0204	0.0093	0.0142
21	Minimum cycle parking in new developments	1	5	1	5	3	0.0482	0.0306	0.0465	0.0440
26	Freight windows	1	1	1	5	1	0.0482	0.0613	0.0093	0.0352
28	Strict liability legislation	1	4	5	5	5	0.0482	0.0123	0.0372	0.0366
29	Workplace crèches	3	1	5	5	1	0.0161	0.0204	0.0093	0.0142
30	Flexible working hours	3	1	5	5	1	0.0161	0.0204	0.0093	0.0142
31	Green belt	1	5	5	5	5	0.0482	0.0123	0.0465	0.0403
33	Smart 'oyster-style' cards for all mobility	3	1	3	5	3	0.0161	0.0204	0.0093	0.0142
34	Mandatory ring fencing of WaC funds	1	5	3	5	5	0.0482	0.0153	0.0465	0.0409
36	All city parking for private car to be pay and display or permit	1	1	3	5	1	0.0482	0.0306	0.0093	0.0291
38	Removal of 'rat runs' for motorised vehicles	1	1	1	5	1	0.0482	0.0613	0.0093	0.0352
42	Velib-style cycle hire scheme (including 'accessible' bikes)	5	5	3	5	3	0.0096	0.0204	0.0465	0.0265
47	Dutch-style railway parking facilities	5	3	4	5	3	0.0096	0.0175	0.0279	0.0185
52	Community leisure walks and bicycle rides	1	1	1	3	5	0.0482	0.0204	0.0056	0.0256
53	Walking buses to school for young children	1	3	1	5	5	0.0482	0.0204	0.0279	0.0345
54	On-road cycle paths	3	5	3	5	1	0.0161	0.0306	0.0465	0.0311
56	Pavement widening	5	5	4	5	1	0.0096	0.0245	0.0465	0.0273
57	Dutch-style segregated cycle paths	5	5	5	5	1	0.0096	0.0204	0.0465	0.0265
61	Mandatory 'core' WaC networks	5	5	5	5	3	0.0096	0.0153	0.0465	0.0255
70	Widespread private car-sharing schemes	3	1	3	3	3	0.0161	0.0204	0.0056	0.0127
72	City-wide 20mph speed limit	1	5	3	5	3	0.0482	0.0204	0.0465	0.0419
75	Limits on car advertising	1	2	1	1	5	0.0482	0.0204	0.0037	0.0248
78	Contra-flow bicycle lanes in one way streets	1	5	1	5	1	0.0482	0.0613	0.0465	0.0501
79	Public fitness campaign	3	2	1	1	3	0.0161	0.0306	0.0037	0.0140
86	Smart bicycle storage units	4	4	4	5	1	0.0120	0.0245	0.0372	0.0246
87	Cycle traffic enforcement	3	3	1	5	1	0.0161	0.0613	0.0279	0.0298
94	Retrofitting cul-de-sacs for WaC connectivity	4	5	3	5	1	0.0120	0.0306	0.0465	0.0295
103	Private motor vehicle ownership restrictions	1	5	1	5	3	0.0482	0.0306	0.0465	0.0440
112	Car free housing developments	1	5	5	5	3	0.0482	0.0153	0.0465	0.0409
115	Consolidated neighbourhood goods delivery	3	1	3	5	1	0.0161	0.0306	0.0093	0.0163
118	Orange NEV/HPV routes 20mph	5	3	5	5	3	0.0096	0.0153	0.0279	0.0181

A.6 Traditional Implementation Complexity Ranking in the Second Case Study

		<i>Technical complexity</i>	Public (un)acceptability	<i>Institutional complexity</i>	Weighted complexity of the measure
		0.2	0.4	0.4	
2	All PT fully accessible	1	1	1	1
3	Maintenance of WaC infrastructure	1	1	1	1
6	Regular public realm maintenance/cleaning	1	1	1	1
7	Widespread Sheffield stands	1	1	1	1
8	Opt-out travel training for all school children	3	1	3	2.2
10	Fine-grained provision of quality public space	3	1	5	3
11	Raised pedestrian crossings instead of dropped kerbs	1	4	1	2.2
13	Tree planting/greenery	1	1	3	1.8
21	Minimum cycle parking in new developments	1	1	2	1.4
26	Freight windows	3	4	5	4.2
28	Strict liability legislation	1	5	5	4.2
29	Workplace crèches	5	1	5	3.4
30	Flexible working hours	5	3	5	4.2
31	Green belt	5	5	5	5
33	Smart 'oyster-style' cards for all mobility	5	1	3	2.6
34	Mandatory ring fencing of WaC funds	1	1	3	1.8
36	All city parking for private car to be pay and display or permit	1	3	1	1.8
38	Removal of 'rat runs' for motorised vehicles	1	3	1	1.8
42	Velib-style cycle hire scheme (including 'accessible' bikes)	3	1	1	1.4
47	Dutch-style railway parking facilities	3	1	3	2.2
52	Community leisure walks and bicycle rides	1	1	1	1
53	Walking buses to school for young children	1	1	3	1.8
54	On-road cycle paths	1	3	1	1.8
56	Pavement widening	3	2	3	2.6
57	Dutch-style segregated cycle paths	5	2	5	3.8
61	Mandatory 'core' WaC networks	5	1	3	2.6
70	Widespread private car-sharing schemes	1	1	1	1
72	City-wide 20mph speed limit	1	4	1	2.2
75	Limits on car advertising	1	1	5	2.6
78	Contra-flow bicycle lanes in one way streets	1	3	1	1.8
79	Public fitness campaign	1	1	1	1
86	Smart bicycle storage units	3	1	3	2.2
87	Cycle traffic enforcement	1	3	1	1.8
94	Retrofitting cul-de-sacs for WaC connectivity	5	3	3	3.4
103	Private motor vehicle ownership restrictions	5	5	5	5
112	Car free housing developments	1	3	1	1.8
115	Consolidated neighbourhood goods delivery	3	1	3	2.2
118	Orange NEV/HPV routes 20mph	5	3	3	3.4

A.7 Network Centric Performance Ranking in the Second Case Study

#	MEASURE TITLE	Cost (C)	Effectiveness (E)	Timescale of implementation (T)	Timescale of lasting implementation effect (L.T)	Time from end of implementation to effect being felt (delay) (D)	Utility value of total cost	Utility value of total implementation time	Utility value of total length of effect	Weighted value of measures and their preconditions
							0.4	0.2	0.4	
2	All PT fully accessible	3	1	3	5	1	0.0233	0.0437	0.0093	0.0218
3	Maintenance of WaC infrastructure	5	5	3	3	1	0.0140	0.0437	0.0279	0.0255
6	Regular public realm maintenance/cleaning	3	3	1	1	3	0.0087	0.0146	0.0056	0.0086
7	Widespread Sheffield stands	3	3	3	5	3	0.0087	0.0159	0.0279	0.0178
8	Opt-out travel training for all school children	3	1	3	5	5	0.0233	0.0218	0.0093	0.0174
10	Fine-grained provision of quality public space	5	3	5	5	3	0.0054	0.0092	0.0279	0.0151
11	Raised pedestrian crossings instead of dropped kerbs	3	1	5	5	1	0.0233	0.0291	0.0093	0.0189
13	Tree planting/greenery	3	1	3	5	3	0.0054	0.0092	0.0093	0.0077
21	Minimum cycle parking in new developments	1	5	1	5	3	0.0117	0.0194	0.0465	0.0271
26	Freight windows	1	1	1	5	1	0.0175	0.0291	0.0093	0.0165
28	Strict liability legislation	1	4	5	5	5	0.0699	0.0175	0.0372	0.0463
29	Workplace crèches	3	1	5	5	1	0.0233	0.0291	0.0093	0.0189
30	Flexible working hours	3	1	5	5	1	0.0233	0.0291	0.0093	0.0189
31	Green belt	1	5	5	5	5	0.0699	0.0175	0.0465	0.0501
33	Smart 'oyster-style' cards for all mobility	3	1	3	5	3	0.0233	0.0291	0.0093	0.0189
34	Mandatory ring fencing of WaC funds	1	5	3	5	5	0.0699	0.0218	0.0465	0.0509
36	All city parking for private car to be pay and display or permit	1	1	3	5	1	0.0699	0.0437	0.0093	0.0404
38	Removal of 'rat runs' for motorised vehicles	1	1	1	5	1	0.0699	0.0873	0.0093	0.0492
42	Velib-style cycle hire scheme (including 'accessible' bikes)	5	5	3	5	3	0.0047	0.0097	0.0465	0.0224
47	Dutch-style railway parking facilities	5	3	4	5	3	0.0140	0.0250	0.0279	0.0217
52	Community leisure walks and bicycle rides	1	1	1	3	5	0.0699	0.0291	0.0056	0.0360
53	Walking buses to school for young children	1	3	1	5	5	0.0117	0.0175	0.0279	0.0193
54	On-road cycle paths	3	5	3	5	1	0.0233	0.0437	0.0465	0.0366
56	Pavement widening	5	5	4	5	1	0.0140	0.0349	0.0465	0.0312
57	Dutch-style segregated cycle paths	5	5	5	5	1	0.0070	0.0159	0.0465	0.0246
61	Mandatory 'core' WaC networks	5	5	5	5	3	0.0050	0.0070	0.0465	0.0220
70	Widespread private car-sharing schemes	3	1	3	3	3	0.0233	0.0291	0.0056	0.0174
72	City-wide 20mph speed limit	1	5	3	5	3	0.0699	0.0291	0.0465	0.0524
75	Limits on car advertising	1	2	1	1	5	0.0699	0.0291	0.0037	0.0353
78	Contra-flow bicycle lanes in one way streets	1	5	1	5	1	0.0175	0.0291	0.0465	0.0314
79	Public fitness campaign	3	2	1	1	3	0.0233	0.0437	0.0037	0.0195
86	Smart bicycle storage units	4	4	4	5	1	0.0175	0.0349	0.0372	0.0289
87	Cycle traffic enforcement	3	3	1	5	1	0.0175	0.0146	0.0279	0.0211
94	Retrofitting cul-de-sacs for WaC connectivity	4	5	3	5	1	0.0175	0.0437	0.0465	0.0343
103	Private motor vehicle ownership restrictions	1	5	1	5	3	0.0078	0.0109	0.0465	0.0239
112	Car free housing developments	1	5	5	5	3	0.0041	0.0058	0.0465	0.0214
115	Consolidated neighbourhood goods delivery	3	1	3	5	1	0.0175	0.0291	0.0093	0.0165
118	Orange NEV/HPV routes 20mph	5	3	5	5	3	0.0039	0.0073	0.0279	0.0142

A.8 Network Centric Implementation Complexity Ranking in the Second Case Study

		<i>Technical complexity</i>	<i>Public (un)acceptability</i>	<i>Institutional complexity</i>	<i>Total technical complexity</i>	<i>Total public unacceptability complexity</i>	<i>Total institutional complexity</i>	<i>Weighted complexity of the measure and preconditions</i>
		0.2	0.4	0.4				
2	All PT fully accessible	1	1	1	1	1	1	1
3	Maintenance of WaC infrastructure	1	1	1	1	1	1	1
6	Regular public realm maintenance/cleaning	1	1	1	4	2	6	4
7	Widespread Sheffield stands	1	1	1	4	3	4	3.6
8	Opt-out travel training for all school children	3	1	3	3	1	3	2.2
10	Fine-grained provision of quality public space	3	1	5	7	4	11	7.4
11	Raised pedestrian crossings instead of dropped kerbs	1	4	1	1	4	1	2.2
13	Tree planting/greenery	1	1	3	7	4	11	7.4
21	Minimum cycle parking in new developments	1	1	2	4	3	5	4
26	Freight windows	3	4	5	6	5	8	6.4
28	Strict liability legislation	1	5	5	1	5	5	4.2
29	Workplace crèches	5	1	5	5	1	5	3.4
30	Flexible working hours	5	3	5	5	3	5	4.2
31	Green belt	5	5	5	5	5	5	5
33	Smart 'oyster-style' cards for all mobility	5	1	3	5	1	3	2.6
34	Mandatory ring-fencing of WaC funds	1	1	3	1	1	3	1.8
36	All city parking for private car to be pay and display or permit	1	3	1	1	3	1	1.8
38	Removal of 'rat runs' for motorised vehicles	1	3	1	1	3	1	1.8
42	Velib-style cycle hire scheme (including 'accessible' bikes)	3	1	1	7	3	7	5.4
47	Dutch-style railway parking facilities	3	1	3	3	1	3	2.2
52	Community leisure walks and bicycle rides	1	1	1	1	1	1	1
53	Walking bus to school for young children	1	1	3	2	2	4	2.8
54	On-road cycle paths	1	3	1	1	3	1	1.8
56	Pavement widening	3	2	3	3	2	3	2.6
57	Dutch-style segregated cycle paths	5	2	5	8	4	8	6.4
61	Mandatory 'core' WaC networks	5	1	3	10	7	10	8.8
70	Widespread private car-sharing schemes	1	1	1	1	1	1	1
72	City-wide 20mph speed limit	1	4	1	1	4	1	2.2
75	Limits on car advertising	1	1	5	1	1	5	2.6
78	Contra-flow bicycle lanes in one way streets	1	3	1	2	6	2	3.6
79	Public fitness campaign	1	1	1	1	1	1	1
86	Smart bicycle storage units	3	1	3	3	1	3	2.2
87	Cycle traffic enforcement	1	3	1	2	8	6	6
94	Retrofitting cul-de-sacs for WaC connectivity	5	3	3	5	3	3	3.4
103	Private motor vehicle ownership restrictions	5	5	5	11	7	9	8.6
112	Car-free housing developments	1	3	1	9	7	7	7.4
115	Consolidated neighbourhood goods delivery	3	1	3	6	5	8	6.4
118	Orange NEV/HPV routes 20mph	5	3	3	12	8	8	8.8

A.9 Agent-Based Modelling Code

The source codes for the agents, visualizations and the custom user panel in the Repast Symphony Agent Base Modelling Toolkit are roughly 6000 lines. If they were to be printed, the length of the codes would have been longer than the thesis itself. Therefore, the source codes are not printed in the thesis, but they are accessible from the following address along with other relevant details:

Preferred address: <http://db.tt/AXP3dq50>

Backup address: https://spideroak.com/browse/share/DPHIL_THESIS/OXFORD2011_

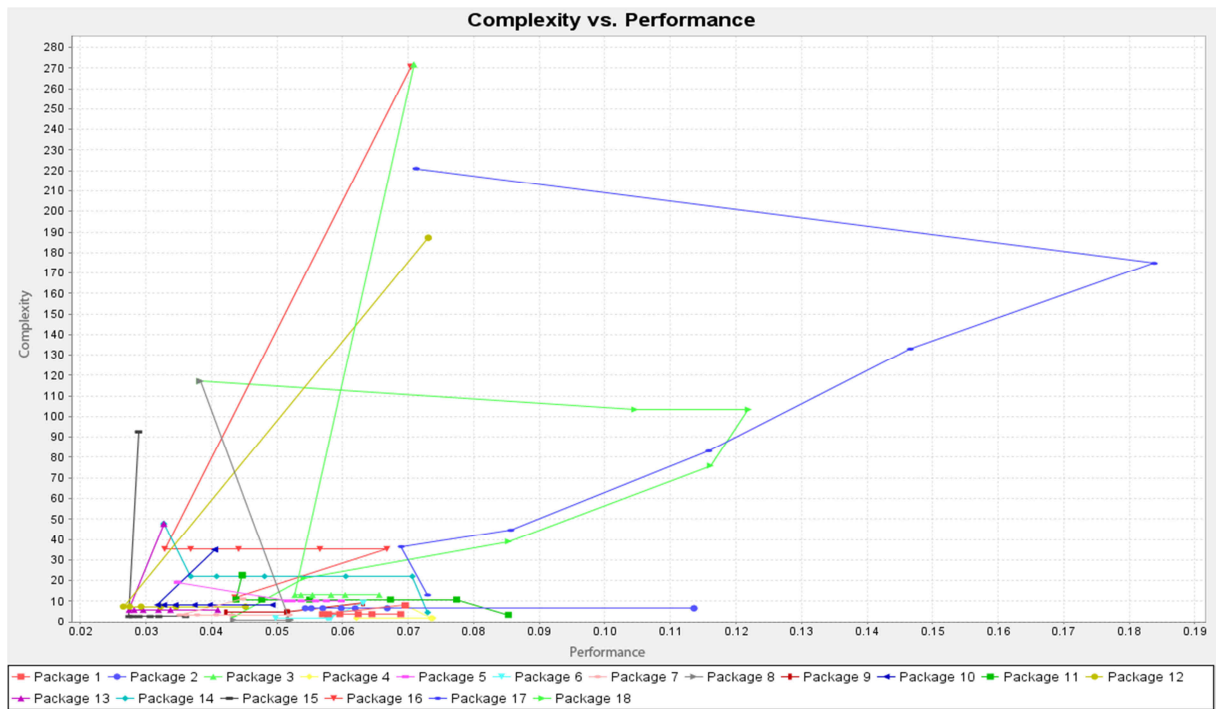
The breakdown of the ABM code:

- Policy Packer and PPScheduler Agents: 40%
- Model Initialization and Miscellaneous Codes: 30%
- Custom User Panel and Visualizations: 30%
- Assessor Agent: 10%

Important directories in the ABM model:

- Src: Contains the source codes
- Lib: Contains the external Java library files used
- Data: Contains the policy measure properties and their interactions
- .rs: Contains the score file, and the details of the runtime environment parameters and visual styles (datasets, displays, charts, etc.)
- Doc: Contains the automatically generated documentation of the source codes

A.10 Complexity vs. Performance Score of the Policy Packages and Measures Discussed in Figure 7-6.



A.11 Policy Packaging Workshop

Aside from academics and policy experts, the framework, methodologies and the support tool have created an interest among practitioners. An analysis and a workshop conducted based on a mid-sized city's data is presented here.

Criteria:

Effectiveness criteria:

User benefits (scheme benefits across more potential user groups by age, mode...)

Geographical benefits (how widespread geographically might the benefits be)

Public health benefits

Implementation criteria:

Cost

Funding risk

Engineering/technical feasibility

Partnership involvement

Political/community support

Types of relations:

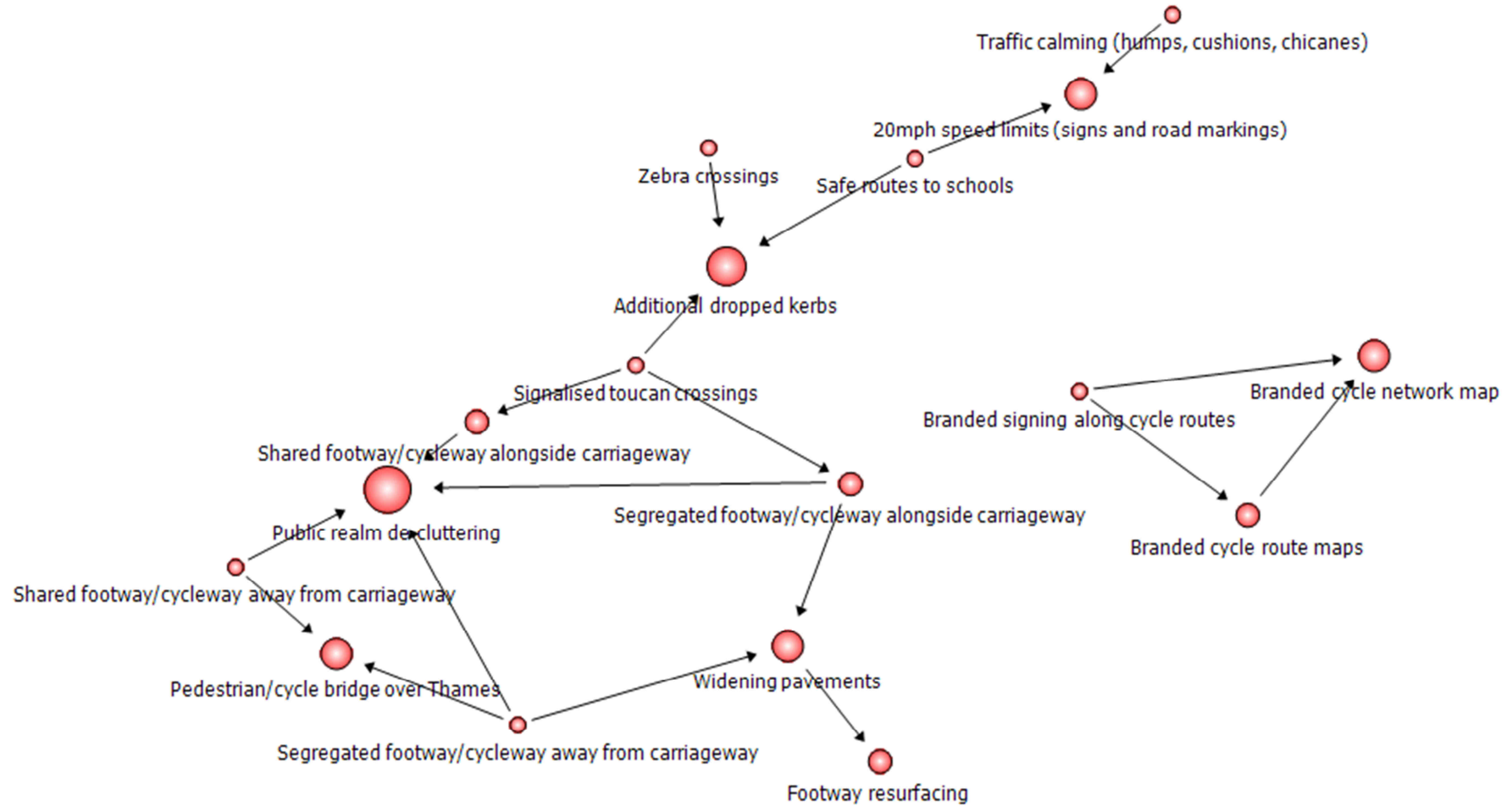
Whether the relation between 'Measure X and Measure Y' can be best described as:

- (P) Preconditional (i.e. X must be implemented before Y can be implemented)
- (F) Faciliatory (i.e. X would improve the effectiveness/implementation of Y)
- (S) Synergistic (i.e. X and Y would improve effectiveness/implementation of each other)
- (PC) potential contradictory' (i.e. X and Y might be detrimental to each other in terms of effectiveness/implementation)
- (C) contradictory' (i.e. X would be detrimental to the effectiveness or implementation of Y)
- (.) insignificant (i.e. X and Y are not related in any of the ways described above)

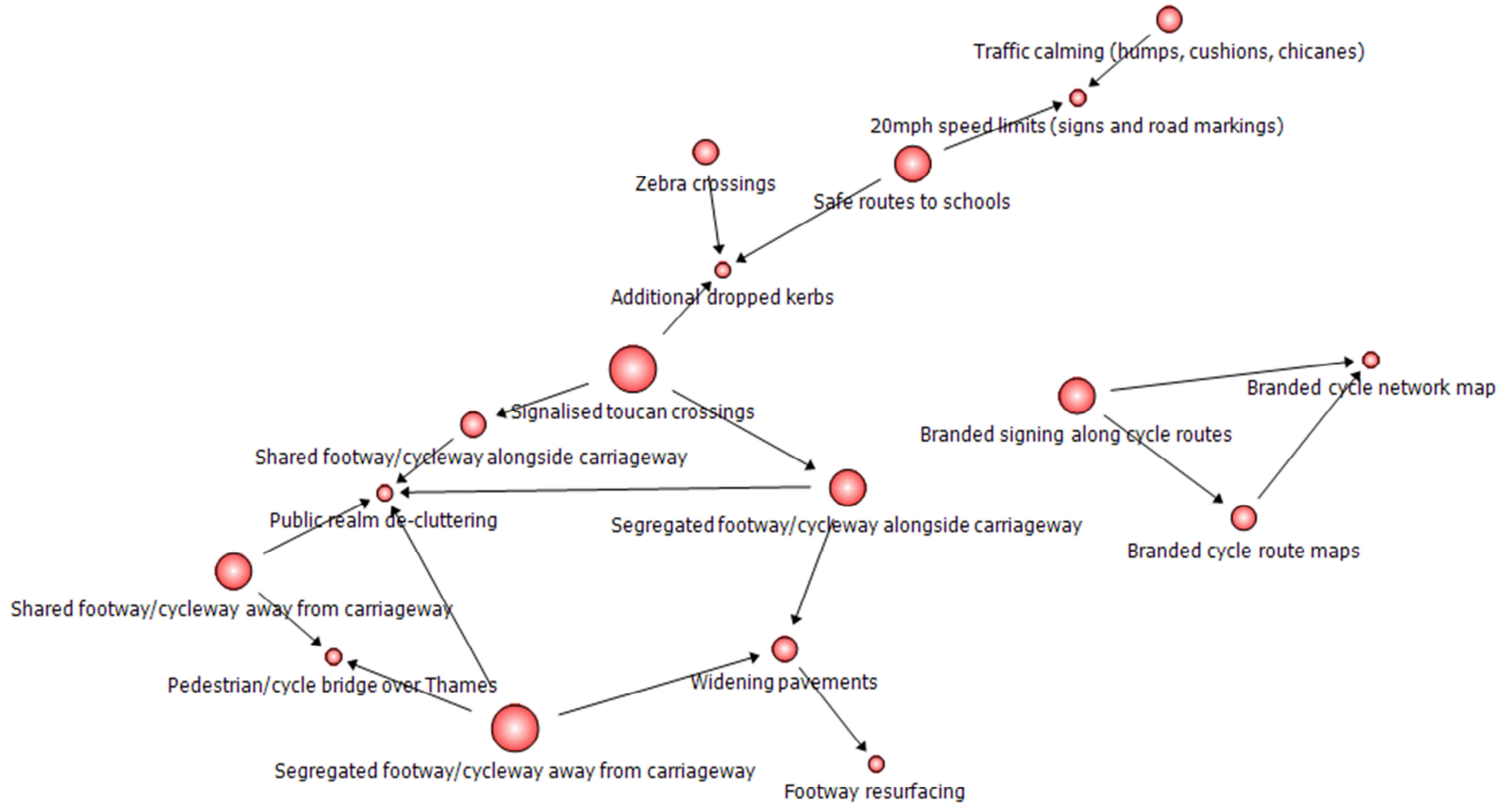
Library of Measures:

#	MEASURE TITLE	Measure Properties							
		Cost	Funding risk	Engineering/technical feasibility	Partnership involvement	Political/community support	User benefits	Geographical benefits	Public health benefits
1	Public transport trip-based smartcard cycle hire	High	Medium	Medium	High	High	Medium	High	High
2	Long-term rental cycle hire	High	Medium	Medium	High	High	Low	Medium	Medium
3	Short-term 'free' with membership/deposit cycle hire	High	High	High	High	High	Low	High	High
4	Low-carbon pedestrian level white street lighting	Low	Low	Medium	Medium	Medium	High	Medium	Medium
5	20mph speed limits (signs and road markings)	Low	Low	Low	High	High	High	Medium	High
6	Traffic calming (humps, cushions, chicanes)	Medium	Medium	Medium	Low	Low	Low	Low	Medium
7	Additional dropped kerbs	Low	Low	Medium	Low	Low	Medium	Low	Low
8	Widening pavements	Medium	Low	Medium	Low	Medium	Medium	Low	Medium
9	On-carriageway cycle lanes	Low	Low	Low	Low	Medium	Low	Low	Low
10	On-carriageway bus lanes with permitted cycling	Low	Low	Low	Medium	Medium	Medium	Low	Medium
11	On-carriageway contra-flow cycle lanes	Medium	Low	Medium	Low	Medium	Low	Low	Medium
12	On-carriageway contra-flow bus lanes with permitted cycling	Medium	Low	Medium	Medium	Medium	Medium	Low	Medium
13	Shared footway/cycleway alongside carriageway	Low	Low	Low	Low	Low	Low	Low	Medium
14	Segregated footway/cycleway alongside carriageway	Low	Low	Low	Low	Low	Medium	Low	Medium
15	Shared footway/cycleway away from carriageway	Medium	Low	Low	Medium	Medium	Medium	Low	Medium
16	Segregated footway/cycleway away from carriageway	Medium	Low	Low	Medium	Medium	Medium	Low	Medium
17	Branded cycle network map	Low	Low	Low	Low	High	Medium	High	Medium
18	Branded cycle route maps	Low	Low	Low	Low	High	Medium	High	Medium
19	Branded signing along cycle routes	Low	Low	Low	Low	Medium	Low	Medium	Medium
20	Bikeability cycle training for children	Low	Low	Low	Medium	High	Low	High	High
21	Cycle training/awareness courses for adults	Low	Low	Low	Medium	Medium	Low	High	High
22	Public health campaign on walking/cycling	Low	Low	Low	High	Medium	Medium	High	High
23	Signalised toucan crossings	Medium	Low	Medium	Low	Low	Medium	Low	Medium
24	Zebra crossings	Medium	Low	Medium	Low	Medium	Low	Low	Medium
25	Sheffield Stand Cycle Parking	Low	Low	Low	Low	High	Low	Medium	Low
26	Advanced stop lines	Low	Low	Low	Low	Medium	Low	Low	Low
27	Workplace travel planning	Low	Low	Low	High	Medium	High	High	Medium
28	Residential travel planning	Low	Low	Low	Medium	Medium	High	Medium	Medium
29	School travel planning	Low	Low	Low	High	Medium	High	Medium	Medium
30	Social media campaigns	Low	Low	Low	High	Medium	High	High	Medium
31	Cycling or walking competitions	Low	Low	Low	Medium	High	Medium	Low	Medium
32	Cycling or walking events	Low	Low	Low	Medium	High	Medium	High	Medium
33	Safe routes to schools	Medium	Low	Medium	Medium	Medium	High	Medium	High
34	Strategic walking network	Medium	Medium	Medium	Low	Low	Medium	High	High
35	Pedestrian/cycle bridge over Thames	High	High	High	Medium	High	Medium	Medium	High
36	Public realm de-cluttering	Medium	Low	Medium	Low	High	High	Medium	Medium
37	Footway resurfacing	Medium	Low	Medium	Low	High	Medium	Medium	Medium
38	Carriageway resurfacing	High	Low	Medium	Low	High	High	Medium	Medium
39	Planting trees	Medium	Low	Medium	Low	High	High	Medium	High
40	Low Emission Zone for lorries	Medium	Medium	Medium	Medium	Medium	High	High	High

Precondition Network (In degrees) => The larger the size of the node means it serves as precondition to more policy measures



Precondition Network (Out degrees) => The larger the size of the node means it has more precondition requirements



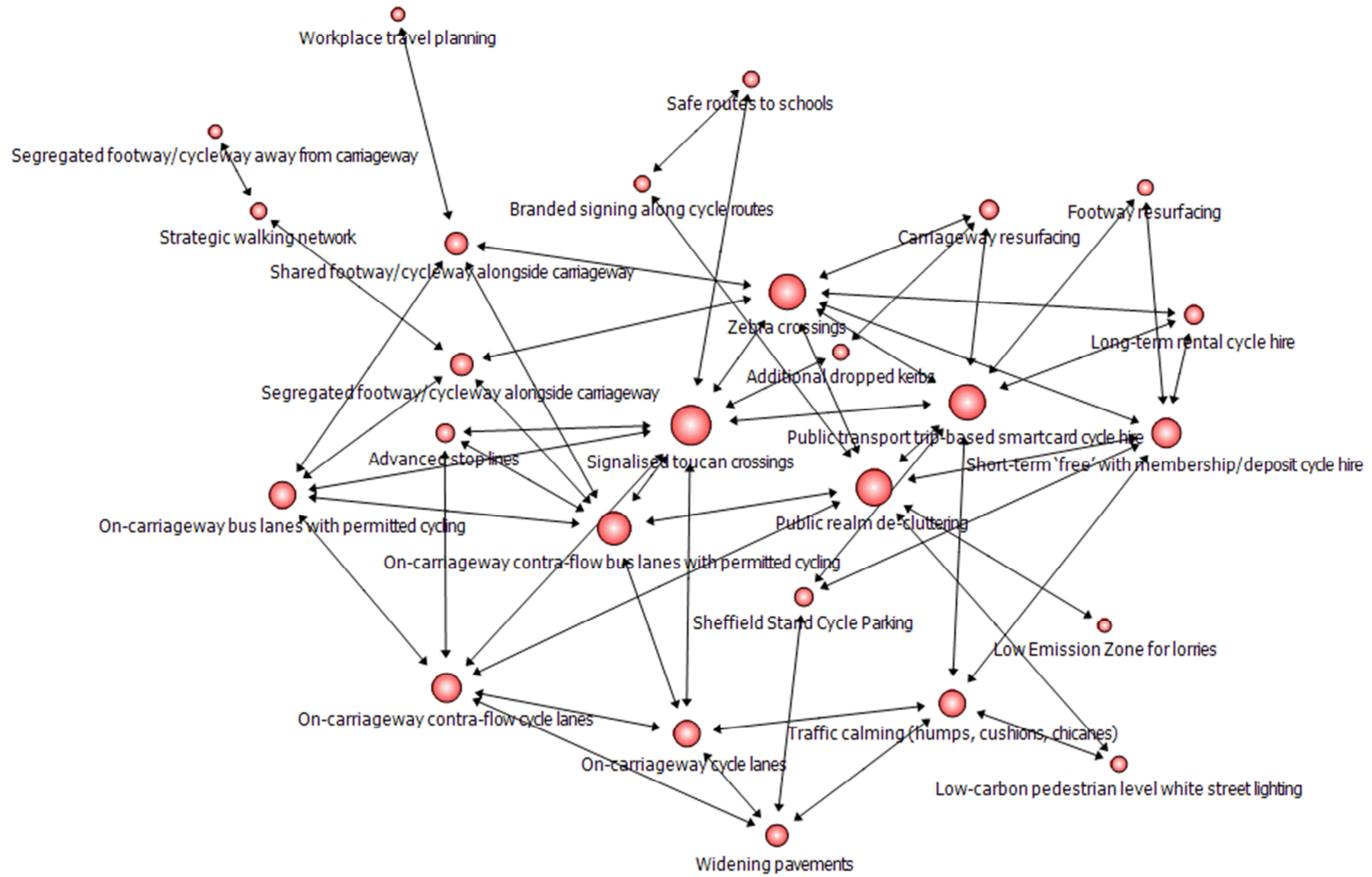
Facilitation Network (In degrees) => The larger the size of the node means it facilitates more policy measures



Facilitation Network (Out degrees) => The larger the size of the node means it is facilitated by more policy measures



Potential Contradiction Network => The larger the size of the node means it has more potential contradictions with other policy measures



Facilitation List

Policy Measure	Out-degree in Facilitation Network	In-degree in Facilitation Network
Public transport trip-based smartcard cycle hire	10	1
Long-term rental cycle hire	20	0
Short-term 'free' with membership/deposit cycle hire	13	1
Low-carbon pedestrian level white street lighting	3	12
20mph speed limits (signs and road markings)	4	13
Traffic calming (humps, cushions, chicanes)	1	6
Additional dropped kerbs	4	6
Widening pavements	4	16
On-carriageway cycle lanes	4	7
On-carriageway bus lanes with permitted cycling	4	7
On-carriageway contra-flow cycle lanes	5	7
On-carriageway contra-flow bus lanes with permitted cycling	4	7
Shared footway/cycleway alongside carriageway	7	11
Segregated footway/cycleway alongside carriageway	6	8
Shared footway/cycleway away from carriageway	6	10
Segregated footway/cycleway away from carriageway	5	9
Branded cycle network map	6	10
Branded cycle route maps	6	12
Branded signing along cycle routes	2	20
Bikeability cycle training for children	15	8
Cycle training/awareness courses for adults	17	9
Public health campaign on walking/cycling	5	0
Signalised toucan crossings	4	11
Zebra crossings	8	4
Sheffield Stand Cycle Parking	17	5
Advanced stop lines	5	7
Workplace travel planning	14	0
Residential travel planning	20	2
School travel planning	12	0
Social media campaigns	1	18
Cycling or walking competitions	25	1
Cycling or walking events	11	1
Safe routes to schools	7	10
Strategic walking network	3	3
Pedestrian/cycle bridge over Thames	1	7
Public realm de-cluttering	6	6
Footway resurfacing	7	15
Carriageway resurfacing	4	22
Planting trees	4	0
Low Emission Zone for lorries	1	9

Effectiveness and Implementation Rankings

MEASURE TITLE	Effectiveness Ranking			MEASURE TITLE	Implementation ranking		
Segregated footway/cycleway away from carriageway	1		Weights used:	Segregated footway/cycleway away from carriageway	1		Weights used:
Safe routes to schools	2		user benefits (50%);	20mph speed limits (signs and road markings)	2		cost (40%);
Shared footway/cycleway away from carriageway	3		geographical benefits (20%);	Low-carbon pedestrian level white street lighting	3		funding risk (15%);
Segregated footway/cycleway alongside carriageway	4		Public Health benefits (30%);	Bikeability cycle training for children	4		feasibility (15%);
Signalised toucan crossings	5			Cycling or walking competitions	4		partnership involvement (10%)
Branded signing along cycle routes	6			Cycling or walking events	4		political/community support (20%)
Branded cycle route maps	7			Public health campaign on walking/cycling	7		
Traffic calming (humps, cushions, chicanes)	8			Workplace travel planning	7		
Widening pavements	9			School travel planning	7		
Shared footway/cycleway alongside carriageway	9			Social media campaigns	7		
Low Emission Zone for lorries	11			Shared footway/cycleway away from carriageway	11		
20mph speed limits (signs and road markings)	12			Branded cycle network map	12		
Planting trees	12			Sheffield Stand Cycle Parking	12		
Workplace travel planning	14			On-carriageway bus lanes with permitted cycling	14		
Social media campaigns	14			Cycle training/awareness courses for adults	14		
Public transport trip-based smartcard cycle hire	16			Residential travel planning	14		
Low-carbon pedestrian level white street lighting	16			Safe routes to schools	17		
Public health campaign on walking/cycling	16			Additional dropped kerbs	18		
Residential travel planning	16			On-carriageway cycle lanes	19		
School travel planning	16			Advanced stop lines	19		
Strategic walking network	16			Branded signing along cycle routes	21		
Public realm de-cluttering	16			Branded cycle route maps	22		
Carriageway resurfacing	16			Segregated footway/cycleway alongside carriageway	23		
Pedestrian/cycle bridge over Thames	24			Widening pavements	24		
Zebra crossings	25			Traffic calming (humps, cushions, chicanes)	25		
Branded cycle network map	26			Signalised toucan crossings	26		
Cycling or walking events	26			Public realm de-cluttering	27		
Short-term 'free' with membership/deposit cycle hire	28			Footway resurfacing	27		
Bikeability cycle training for children	28			Planting trees	27		
Cycle training/awareness courses for adults	28			On-carriageway contra-flow bus lanes with permitted cycling	30		
Footway resurfacing	28			Zebra crossings	31		
On-carriageway bus lanes with permitted cycling	32			Short-term 'free' with membership/deposit cycle hire	32		
On-carriageway contra-flow bus lanes with permitted cycling	32			Shared footway/cycleway alongside carriageway	33		
Cycling or walking competitions	32			On-carriageway contra-flow cycle lanes	34		
Long-term rental cycle hire	35			Carriageway resurfacing	35		
Additional dropped kerbs	35			Pedestrian/cycle bridge over Thames	36		
On-carriageway contra-flow cycle lanes	37			Public transport trip-based smartcard cycle hire	37		
Sheffield Stand Cycle Parking	38			Long-term rental cycle hire	37		
On-carriageway cycle lanes	39			Low Emission Zone for lorries	39		
Advanced stop lines	39			Strategic walking network	40		

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